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Shoalwater Bay Defence Training Area Dugong Research Program Underwater Blast Measurements

Phillip Box, Frank Marian
and Darren Wiese

DSTO-TR-1024

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Maritime Platforms Division
Aeronautical and Maritime Research Laboratory

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ABSTRACT

Defence training in Shoalwater Bay, Queensland includes the training of RAN clearance divers in underwater explosives demolition. Shoalwater Bay is also a significant dugong habitat and concerns have been raised about the impact of diver training on resident dugong.
Shock parameters resulting from underwater detonations during a clearance diver training exercise were measured. The methodology, results, analysis and recommendations are presented.

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Executive Summary

Detonations underwater are an integral component of RAN Clearance Diver Training. Regular training exercises are conducted in Shoalwater Bay, Queensland on Triangular Island in the east of the Shoalwater Bay Defence Training Area. Shoalwater Bay is also the home to the largest population of dugongs in the Great Barrier Reef Marine Park south of Hinchinbrook Channel.

Concerns raised about the possible impact on the dugong population of defence activities within Shoalwater Bay resulted in Defence managing four dugong research projects. As part of one of these projects shock parameters were measured during a RAN Clearance Diver training exercise.

The methodology, results and analysis are presented. Recommendations for clearance diver explosive demolition training activities are discussed. Results indicate that the safe distance for dugong would be less than 1 km from the detonation site.

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Phillip has conducted evaluations of explosives and the effects of explosives on platforms, structures and components, including the measurement of shock and blast parameters from detonations in air and underwater for over 19 years.
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Frank commenced work at AMRL in 1969 and has been involved in a diverse range of activities. Since 1987 he has worked in the area of specialised instrumentation and has conducted field trials and laboratory experiments to measure transient parameters associated with air and underwater blast. In more recent times his work area has focused on experiments related to structural response of naval platforms to underwater detonations.

Darren Wiese
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Darren graduated from Western Metropolitan College of TAFE with an Associate Diploma of Business (Computer Programming). Since joining AMRL in 1982 he has been involved in explosives research as an explosives firing officer and with instrumenting explosives experiments. He has developed software packages for the analysis of blast parameters for air and underwater detonations. More recently Darren manages the transient data acquisition capability within MPD.

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1. Introduction

Triangular Island, within the Shoalwater Bay Defence Training Area (SWBTA) in Queensland, is used by the RAN to train clearance divers in underwater demolition and mine disposal techniques. The two intertidal bay sites used at Triangular Island are considered a key asset to Defence because they permit convenient and safe, yet highly realistic and rigorous training conditions. Clearance Diver training exercises generally take place over a two-week period, two to three times a year.

Shoalwater Bay is also home to the largest dugong population in the Great Barrier Reef Marine Park south of the Hinchinbrook Channel. In 1997, to address the apparent major decline in dugong numbers in the southern half of the GBR, sixteen dugong sanctuaries were declared along the Queensland coast. The Shoalwater Bay Dugong Sanctuary was declared as a category 'A' sanctuary and is considered crucial to the stabilisation and recovery of local dugong numbers.

Concerns have been raised about the possible impact of Clearance Diver Training on the local dugong population. Therefore, as part of the executive level arrangement between Defence, the Great Barrier Reef Marine Park Authority and the Queensland Department of Environment & Heritage, Defence agreed to manage four dugong research projects relating to its activities within Shoalwater Bay, and particularly to clearance diver training and the detonation of underwater ordnance at Triangular Island. The four projects comprised dugong tracking by satellite telemetry, aerial monitoring of dugong movements during training exercises, an anatomical study to determine dugong auditory sensitivity, and measurement of underwater shock parameters during a diver training exercise. For the latter project, personnel from Aeronautical and Maritime Research Laboratory (Maritime Platforms Division) conducted underwater blast measurements during a clearance diver training exercise in November 1999.

This report discusses the technology, methods and results of these measurements.

2. Experimental Procedure

2.1 Location

Shoalwater Bay is located on the central Queensland coast, approximately 550 km north of Brisbane and 115 km north of the Tropic of Capricorn. The semi-enclosed, triangular-shaped bay is bounded in the east by a narrow and hilly peninsula and, off its northern extremity, Townshend Island which is separated from the peninsula by Strong Tide Passage. Triangular Island consists of two low wooded islets located on the south and inner side of Strong Tide Passage.

Diver training at Triangular Island involves the finding of explosive ordnance, relocation to a suitable disposal position and then the disposal of the ordnance by detonation. Although the whole island could be used to locate the ordnance, the detonation of it was primarily conducted in four locations: Big Bang Beach, Little Bang Beach, Barricade Passage and Liclic Beach. Barricade Passage is at the western end of Little Bang Beach and Liclic Beach is on the western end of the island. (Figure 1)

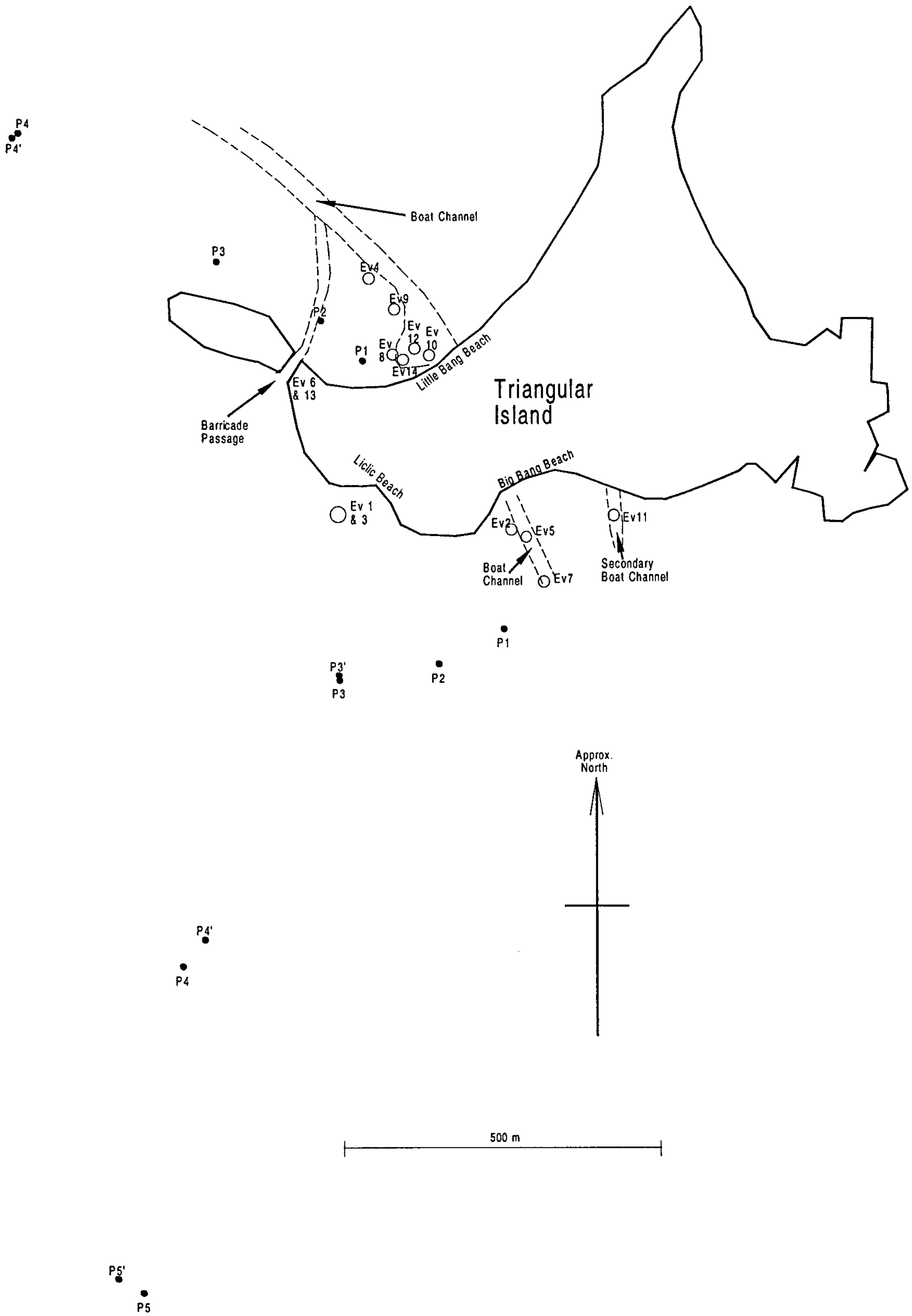


Figure 1 Location of Transducers and Detonation Sites

2.2 Explosive Events

This experiment was conducted on an opportunity basis during Clearance Diver training exercises on Triangular Island. As such a number of detonations were conducted for which it was not possible to record blast parameters. Recording of blast parameters was attempted for a total of 14 detonations. Some of these were specifically located to achieve the worst case blast scenario to maximise the blast pressure records and were initiated with DSTO equipment to ensure synchronisation with the recording instrumentation. The remaining detonations were initiated either non-electrically or electrically with RAN shrike firing units as part of the diver training. Non-electric firings use safety fuse that burns along its length until it initiates a detonator that consequently initiates detonating cord and the main explosive charge. The burn times for the safety fuse are only approximate. Synchronisation with the recording instrumentation for these events proved difficult. Two methods were attempted as described below.

2.3 Transducers

The transducers used to record the underwater blast pressure-time profiles were PCB Integrated Circuit Piezoelectric transducers, model No. 138A01, with a dynamic range of 7 MPa. These transducers utilise a tourmaline crystal housed in a tygon tube filled with silicone oil. The silicone oil, in which the crystal is situated, is of similar shock impedance to the surrounding water. These transducers have been used extensively to characterise and quantify the shock environment during research into shock loading of RAN platforms, structures and components.

These transducers were designed to be suspended vertically and weighted to maintain their position, usually with a fishing sinker. DSTO use a sinker with a mass of 340 grams. This deployment method uses the water surface as a datum and transducers are usually deployed to a set depth. Due to the large tidal movements in Shoalwater Bay the transducers could not be deployed in the normal manner. During this experiment the transducers were deployed from the seabed and "floated" to maintain a consistent height above the seabed. A polystyrene float of 100 mm diameter produces approximately 300 grams of flotation and hence similar tension on the transducer as in other applications.

This deployment method was a compromise between the worst case for a mammal (a dugong) feeding on sea grass, ie on the seabed, and having sufficient free water around the transducer to produce a clean pressure-time history that could be interpreted. Transducers were deployed at a height of 1 meter above the seabed.

A transducer deployed on the mud flats of Little Bang Beach is shown in Figure 2.

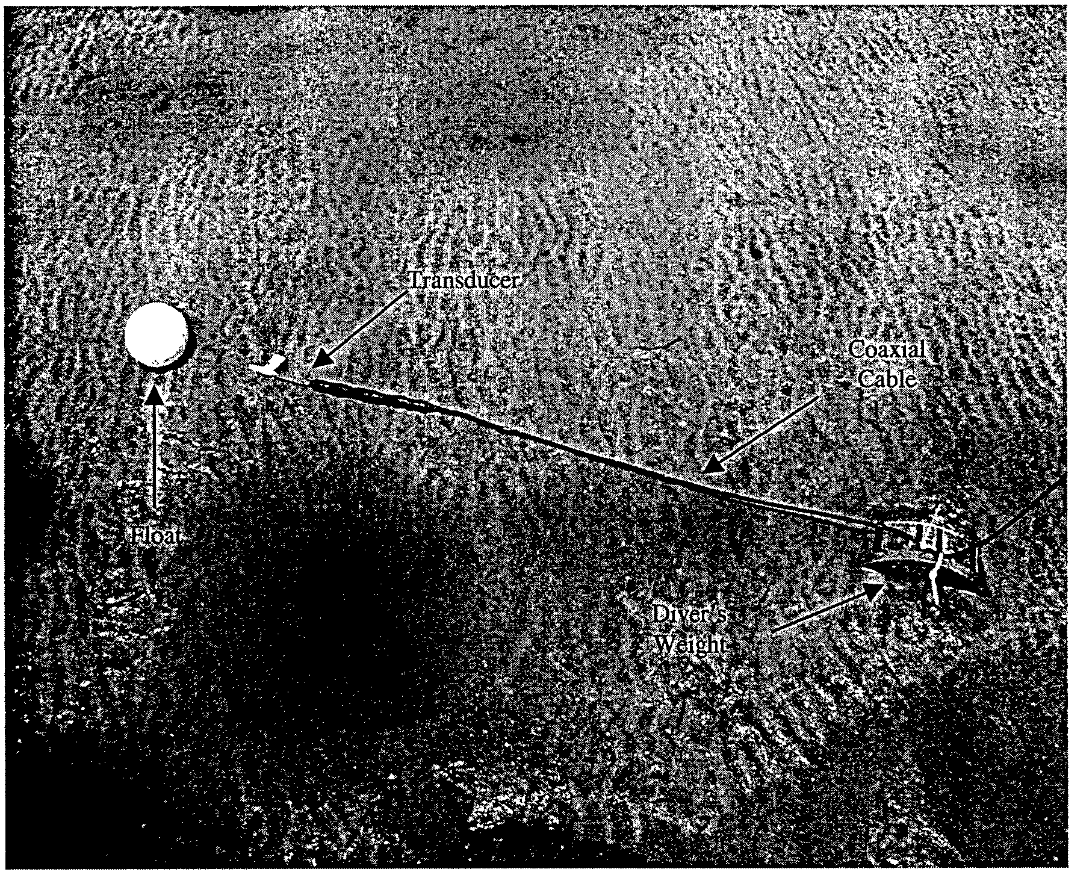


Figure 2 Transducer deployed on mud flat at low tide.

2.4 Transducer Calibration

Prior to shipment for the experiment each of the underwater pressure transducers was broken down, baked in a vacuum oven as per the transducers instruction manual (this removes any moisture from the crystal) and then calibrated against a transfer standard. The transfer standard is calibrated traceable to NIST in compliance with ISO 10012-1. This process involves subjecting the transducer to a series of pseudo dynamic pressure pulses in a purpose built calibration device that consists, in its simplest form, of a cylinder with ports for the insertion of the transducer and transfer standard and a piston onto which a weight is dropped. The resultant half sine-wave pulses from both the transfer standard and the transducer are analysed and the amplitudes used to determine the transfer characteristic of the transducer. The transducers are subjected to at least three pulses at each of five different amplitudes covering the nominal range of the transducer. A linear regression is then used to calculate the sensitivity of the transducer.

2.5 Transducer Cabling

Coaxial cabling, RG59, was deployed from the transducers to the recording instrumentation located in the bunker on the island. Cables, 500 metres in length, were pre-fitted with BNC connectors at both ends. The longest transducer-instrumentation length was 1.5 km in three 500 m sections. The cabling was simply deployed from a cable reel over the transom of a dinghy where possible. Deployment of cabling on Little Bang Beach involved walking the cable out over the mud flats. The connections between the cable lengths were waterproofed by wrapping the BNC to BNC join in amalgamating tape and then covering this with a cold shrink rubber insulation with a silicone compound injected into the void space around the cable inside the cold shrink.

The connection of the cable to the transducer required a BNC to 10/32 Microdot adaptor, model no. 070A03. Initially the end of the transducer, the adaptor and the BNC connector were waterproofed using amalgamating tape. However, several connectors were found to be affected by water ingression. After the affected cable was disposed of and a new connector fitted, amalgamating tape was re-applied and then covered with a section of cold shrink rubber insulation to water proof the connection.

The cabling was left on the seabed, through the water, and on the island suspended above head height to limit damage from other activities.

2.6 Transducer Locations

Transducers were deployed in approximately a southwest direction from Big Bang Beach, which heads towards the East Ridge Bank; a known dugong feeding ground, and a northwesterly direction from Little Bang Beach, towards Strong Tide passage; a probable dugong migratory path. Deployment of transducers in these directions attempted to ensure measurements from detonations in the four main detonation areas and at the same time allowed cables to be deployed in areas where damage from the training activities would be unlikely.

The locations of the transducers were measured using a theodolite positioned on the shore at the western ends of both Big Bang Beach and Little Bang Beach. In this way the relative location of the transducers and detonation sites could be plotted, as is shown in Figure 1.

The transducers were numbered P1 to P5 on Big Bang Beach side of the island and P1 to P4 on the Little Bang Beach side. The transducers P3 to P5 on the Big Bang side required reconnection of the cable connector after water ingression and were consequently moved. Their positions are indicated as P3', P4' and P5'. The same is relevant for P4' on Little Bang Beach side of the island.

The intention was to conduct most of the detonations at high tide but due to numerous reasons some detonations were delayed. The water level on some events was mid tide and consequently no pressure time records were obtained for those events.

2.7 Recording Instrumentation

Pressure signals were recorded on Digistar III digital data recorders. The Digistar recorders provided transducer excitation, amplification, analog-to-digital conversion and digital storage of the data for one transducer. Ten recorders were deployed on the island with each transducer connected directly via the coaxial cable. The data were recorded using a digital sample rate of 1 Million, 16 bit samples per second providing 4 seconds of recording time for each channel.

The Digistars are computer controlled and subsequent to recording the pressure signal, the data were transferred to the computer, converted to ASCII format and analysed using the Origin software package.

2.8 Recording Synchronisation

The recording of pressure signals from detonations requires the synchronisation of the detonation with the instrumentation. DSTO normally perform this synchronisation by using explosive firing systems designed to interface with instrumentation and electronic units with which fixed time delays can be programmed. These units are known as Delay Pulse Generators (DPG). For some events it was possible to utilise DSTO's firing system but was not possible, for most events, without compromising the diver training. Many events were initiated using safety fuse. Safety fuse is a slow burning chemical fuse, which allows personnel, in close proximity to the explosives, to start the burning and then relocate to a safe distance before the detonation.

Initially the recording of pressure-time signals was attempted by using the pressure signal to initiate the recording in the Digistar recorders. This is known as "internal triggering". Unfortunately the pressure signal levels were lower than expected and the trigger levels could not be set to successfully record signals in this way.

For later detonations personnel manually triggered the recorders when the detonations were heard. The recorders were configured to stop recording immediately the trigger signal was received. This enabled the recording of the pressure signals but had the disadvantage of not having any precise time relationship with the detonation.

2.9 Event Description

The following describes each of the detonations where blast measurements were attempted. The equivalent mass of TNT is quoted for each detonation using the equivalence ratios used by RAN and shown in Table 1.

Table 1 Explosive Composition to TNT Equivalence Ratios.

Explosive	TNT Equivalence Ratio
Composition B	1.5
PETN (detonating cord)	1.45
Plastic Explosive	1.2
HBX-3	1.1
H-6	1.24
ANFO	0.56
Hose Charges	1.5

2.9.1 Event 1

The explosives detonated consisted of ten 5"/54 shells, each containing 3.4 kg of Composition B explosive, laid out parallel to each other and connected by short lengths of detonating cord. The total explosive quantity was 34.2 kg, the equivalent of 51.3 kg TNT. The shells were located on the rim of the 'staff swimming hole' on Liclic Beach. The explosives were initiated using safety fuse.

2.9.2 Event 2

The explosives detonated consisted of one Mk 44 Torpedo Warhead, containing 31.8 kg of HBX-3 explosive, 4 sticks of plastic explosives (920 g), and 80 m of detonating cord (800 g). The total explosive quantity was 33.5 kg, the equivalent of 37.2 kg TNT. The warhead was positioned on the western side of the boat channel on Big Bang Beach and was initiated electrically using DSTO explosive firing equipment.

2.9.3 Event 3

The explosives detonated consisted of one Mk 44 Torpedo Warhead, containing 31.8 kg of HBX-3 explosive, five 5"/54 shells, each containing 3.4 kg of Composition B explosive, 9 sticks of plastic explosives (2070 g), and 40 m of detonating cord (400 g). The total explosive quantity was 51.3 kg, the equivalent of 63.5 kg TNT. The explosives were positioned in the 'staff swimming hole' on Liclic Beach and were initiated using safety fuse.

2.9.4 Event 4

The explosives detonated consisted of one Mk 44 Torpedo Warhead, containing 31.8 kg of HBX-3 explosive, five 5"/54 shells, each containing 3.4 kg of Composition B explosive, 9 sticks of plastic explosives (2070 g), and 40 m of detonating cord (400 g). The total explosive quantity was 51.3 kg, the equivalent of 63.5 kg TNT. The explosives were positioned on the western edge of the boat channel on Little Bang Beach and were initiated using safety fuse.

2.9.5 Event 5

The explosives detonated consisted of three Mk 44 Torpedo Warheads, each containing 31.8 kg of HBX-3 explosive, eight 5"/54 shells, each containing 3.4 kg of Composition B explosive, and 14 sticks of plastic explosives (3220 g). The total explosive quantity was 125.8 kg, the equivalent of 149.6 kg TNT. The explosives were positioned on the western edge of the boat channel on Big Bang Beach and were initiated using safety fuse.

2.9.6 Event 6

The explosives detonated consisted of five 5"/54 shells, each containing 3.4 kg of Composition B explosive, 80 sticks of plastic explosives (18.4 kg), two Mk AN 8-3 flexible hose charges, each containing 23.1 kg of explosive, and 60 m of detonating cord (600 g). The total explosive quantity was 82.2 kg, the equivalent of 116.9 kg TNT. The explosives were positioned in Barricade Passage at the western end of Little Bang Beach and were to be initiated using safety fuse. This charge did not fire when planned and was later fitted for electrical firing and was initiated electrically using DSTO explosive firing equipment.

2.9.7 Event 7

The explosives detonated consisted of one Mk 82 Bomb, containing 89 kg of H-6 explosive, 4 sticks of plastic explosives (920 g), and 180 m of detonating cord (1800 g). The total explosive quantity was 91.7 kg, the equivalent of 114.1 kg TNT. The bomb was positioned on the western side of the boat channel on Big Bang Beach and was initiated electrically using DSTO explosive firing equipment.

2.9.8 Event 8

The explosives detonated consisted of two Mk 44 Torpedo Warheads, containing 31.8 kg of HBX-3 explosive, 4 sticks of plastic explosives (920 g), and 80 m of detonating cord (800 g). The total explosive quantity was 65.3 kg, the equivalent of 72.2 kg TNT. The warheads were positioned on the western side of the boat channel on Big Bang Beach and were initiated electrically using DSTO explosive firing equipment.

2.9.9 Event 9

The explosives detonated consisted of six 5"/54 shells, each containing 3.4 kg of Composition B explosive, and 126 sticks of plastic explosives (29 kg). The total explosive quantity was 49.4 kg, the equivalent of 65.4 kg TNT. The explosives were positioned in the boat channel on Little Bang Beach and were initiated using safety fuse.

2.9.10 Event 10

The explosives detonated consisted of 80 kg of ANFO, and 80 sticks of plastic explosives (18.4 kg) and 30m of detonating cord (300 g). The total explosive quantity was 98.7 kg, the equivalent of 66.3 kg TNT. The explosives were positioned in the boat channel on Little Bang Beach and were initiated electrically using DSTO explosive firing equipment.

2.9.11 Event 11

The explosives detonated consisted of one Mk 82 Bomb, containing 89 kg of H-6 explosive, one Mk 44 Torpedo Warhead, containing 31.8 kg of HBX-3 explosive, eight 5"/54 shells, each containing 3.4 kg of Composition B explosive. The total explosive quantity was 148 kg, the equivalent of 186.1 kg. The explosives were positioned in the secondary boat channel on Big Bang Beach and were initiated using safety fuse.

2.9.12 Event 12

The explosives detonated consisted of one Mk 44 Torpedo Warhead, containing 31.8 kg of HBX-3 explosive, eight 5"/54 shells, each containing 3.4 kg of Composition B explosive. The total explosive quantity was 59 kg, the equivalent of 75.8 kg. The explosives were positioned in the 'boat harbour' on Little Bang Beach and were initiated using safety fuse.

2.9.13 Event 13

The explosives detonated consisted of six Mk 44 Torpedo Warheads, containing 31.8 kg of HBX-3 explosive, eight 5"/54 shells, each containing 3.4 kg of Composition B explosive, 32 sticks of plastic explosive (18.4 kg), and 60 m of detonating cord (600 g). The total explosive quantity was 237 kg, the equivalent of 173.6 kg TNT. The explosives were positioned in Barricade Passage at the western end of Little Bang Beach and were initiated using safety fuse.

2.9.14 Event 14

The explosives detonated consisted of one Mk 82 Bomb, containing 89 kg of H-6 explosive, 4 sticks of plastic explosives (920 g), and 80 m of detonating cord (800 g). The total explosive quantity was 90.7 kg, the equivalent of 112.6 kg TNT. The bomb was positioned on the western side of the boat channel on Little Bang Beach and was initiated electrically using DSTO explosive firing equipment

3. Results

3.1 Analysis of Pressure Records

The methods used to interpret underwater blast records when assessing the loading of structures in free water revolve around the impulse of the pressure pulse and then calculating the energy flux density of this signal. Other parameters analysed from underwater pressure records include the peak pressure, the arrival time, the time constant of the decaying pressure-time signal and the bubble period. These parameters are relatively easily derived from pressure-time records recorded from detonations in free water with the explosive charge and transducers at depth. In most cases experiments are designed to acquire as close as possible to classical free water blast pressure records.

This experiment was conducted in shallow water both for the detonating explosives and the transducers. In most cases the detonating explosives were positioned in deep holes, as is normally the case in the diver training exercises. This positioning focuses the blast towards the surface therefore promulgating less blast into the surrounding water than would otherwise be the case.

The complex structure of inconsistent seabed and inconsistent depth along with shallow overall water depths has generated complex pressure-time histories. The one obvious complexity of the pressure-time histories, compared to those of deep-water detonations, is the disturbance of the shock wave by the reflections from the seabed and the rarefractions from the sea surface. This has resulted in numerous short duration peaks and troughs in the pressure data, as opposed to a single classical shock wave as depicted in Figure 3.

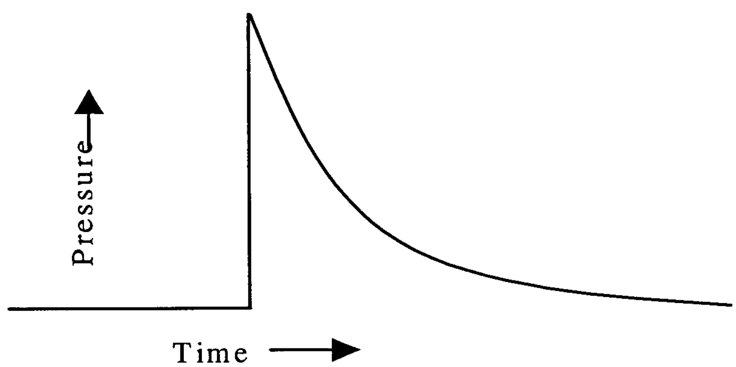


Figure 3 A Classical Pressure-time history

The pressure-time histories for all results obtained are contained in Appendix A.

3.2 Time of Arrival

For the events that were initiated using DSTO equipment the time of arrival could be measured. The time-of-arrival is the time between the explosives detonating and the time of the shock front arriving at the transducer. The recording instrumentation was triggered simultaneously with the electrical energy being discharged through the electric detonator. This is known as Time Zero (TZ). Hence the time axis on the pressure-time histories is referenced to TZ. These detonations used a length of detonating cord between the detonator and the main explosive charge. To calculate a predicted time-of-arrival the length of detonating cord has been accounted for. The Velocity-of-Detonation of the detonating cord is very consistent and for the detonating cord used during these exercises the Velocity-of-Detonation was 7900 m/s. Hence for an eighty metre length of detonating cord, the time from the detonator to the main charge was 80 divided by 7900 which equals 10.1 ms.

The time for a shock wave to travel through water can be calculated using the following formula [1]:

$V_s = 1449.1 + 4.572\,(T) - 0.04453\,(T^2) + 1.398\,(S-35) + 0.017d$

Where: T is the water temperature in Celsius;
S is the salinity of the water in parts per thousand;
and d is the depth of water at the point of interest.

The water temperature was measured as 21° C (with very little variation day to day) and salinity 35.2 ppt. Using an average depth of 3 m the calculated shock velocity is 1525.8 m/s. The explosive to transducer distance and the calculated arrival times are shown in the tables below.

3.3 Peak Pressure

The peak pressures were calculated for each pressure-time history by taking the baseline before any significant excursion as zero pressure and then simply calculating the highest positive peak. This is the blast pressure above the hydrostatic pressures as a result of the detonation.

In the classical pressure pulse Figure 3 the largest pressure value is the first data peak but in this experiment secondary peaks in some cases were the greatest value. The peak pressure quoted is the greatest value in the data. Time-of-arrival and peak pressure results are shown in Table 2.

The blast pressure predictions have been calculated using the similitude equations and coefficients for TNT quoted in Swisdak [1]

3.4 Impulse

The analysis of underwater blast records includes the calculation of the impulse or area under the curve of the pressure pulse. For the classical pressure pulse, as depicted in Figure 3, this calculation is straightforward. The pressure-time histories recorded during this experiment, as stated above, are not classical in shape. The impulse analysis conducted involved the calculation of the area under the curve for both the positive and negative regions of the pressure-time histories for up to five oscillations after the initial peak. This appears to include all significant pressure excursions from the baseline. As the worst case scenario the positive and negative impulses were added to calculate the maximum impulse possible from these results. The impulse values and the accumulated impulses for the positive and negative portions as well as the accumulated absolute values have then been compared with predicted values for impulse from deep-water detonations. The results are shown in Table 3. The blast pressure predictions have been calculated using the similitude equations and coefficients for TNT quoted in Swisdak [1]

Table 2 Time-of-Arrival and Peak Pressure (kPa) Results

Event #	Explosive Mass (TNT equivalent) (kg)	Transducer #	Explosive Transducer Distance (m)	Predicted Time-of-Arrival (ms)	Measured Time-of-Arrival (ms)	Predicted Peak Pressure (deep water) (kPa)	Peak Pressure Measured (kPa)
1	51.3	1	308.1	201.9	N/A	360	<50
		2	276.7	181.3	N/A	400	<32
		3	253.6	166.2	N/A	440	<64
		4	745.1	488.3	N/A	130	<15
		5	1256.5	823.5	N/A	40	<19
2	37.2	1	151.3	109.3	111	700	318
		3	357.4	235.4	242.8	270	16.5
		5	1327	869.7	877.9	60	~1
5	149.6	1	144.1	94.4	N/A	1260	<120
		2	239.6	157.0	N/A	710	<60
		3	369.8	242.4	N/A	430	<40
		4	862.7	565.4	N/A	170	<40
6	116.9	1	121.7	98.3	95.7	1280	7.1
		2	99.2	73.4	71.3	1610	93.6
		3	201.9	144.5	142.71	720	2.7
7	114.1	1	96.2	83.3	90.4	1780	992.4
		2	209.8	160.3	167.8	740	84.3
		5	1282	863.0	865.2	100	8.0
8	72.2	1	49.3	42.4	46.5	3210	640.4
		2	127.4	93.6	96.3	1100	325.1
		3	315.8	217.1	218.2	390	71.3
		4	685	459.1	467.1	160	2.29
9	65.4	1	93.7	61.4	N/A	1500	117.3
		2	117.6	77.1	N/A	1160	52.5
		3	290.2	190.2	N/A	420	27.3
		4	654.1	428.8	N/A	170	1.2
10	66.3	1	104.3	72.4	75.6	1340	77.3
		2	180.5	122.3	124.0	720	47.3
		3	367	244.6	244.9	320	18.8
		4	740.8	489.6	492.9	150	1.09
11	186.1	1	246	161.3	N/A	750	21.1
		2	359.7	235.8	N/A	490	6.9
		4	926.2	607.1	N/A	170	2.2
12	75.8	1	84.6	55.5	N/A	1780	52.6
		2	155.3	101.9	N/A	890	18.1
		3	340	22.9	N/A	370	6.7
13	173.6	1	108	78.4	N/A	2150	14.1
		2	78.5	59.1	N/A	3080	353.4
		3	197.9	137.3	N/A	1080	2.0
14	112.6	1	63.7	51.9	53.8	2840	956.4
		2	141.7	103	104.5	1150	208.7
		3	330.3	226.6	226.3	440	89.8

Table 3 Impulse Results

Event #	Charge mass	Transducer #	Charge - Transducer	Impulse +ve	-ve	+ve	-ve	+ve	-ve	+ve	-ve	+ve	-ve	Accumulated +ve	Accumulated -ve	Accumulated Absolute Impulse	Predicted Impulse
	(kg)		(m)	(Pa.s)	(Pa.s)	(Pa.s)	(Pa.s)	(Pa.s)	(Pa.s)	(Pa.s)	(Pa.s)	(Pa.s)	(Pa.s)	(Pa.s)	(Pa.s)	(Pa.s)	(Pa.s)
2	37.3	P1	151.3	11	33.36	46.01	48.17	74.7	53.51	47.1	97.76			293.4	232.8	526.2	650
		P3	357.4	0.23	1.37	1.33	0.96	1	0.44					2.56	2.77	5.33	300
6	93.8	P1	121.7	0.01	0.04	0.14		0.12	0.02	0.29	0.13	0.52		1.08	0.19	2.27	1400
		P2	99.2	2.32	4.45	4.88	3.33	2.71	1.85	1.15				11.06	9.63	20.69	1680
		P3	201.9	0.04	0.03	0.03	0	0.04	0.02	0.04	0.05			0.15	0.1	0.25	890
7	112.3	P1	96.2	145.4	494.7	692.2								837.6	494.7	1332	1930
		P2	209.8	74.18	124.1	15.38	56.8	61.7	95.45	85.43				236.7	276.3	513	970
		P5	1282	0.07	0.74	1.24	0.31	1.32	1.7	3.03	3.55			5.66	6.3	11.96	190
8	72.3	P1	49.3	16.67	32.13	26.21	21.15							42.88	53.28	96.16	2660
		P2	127.4	3.87	5.26	6.72	8.71	8.94	11.25	7.34				26.87	25.22	52.09	1140
		P3	315.8	0.61	1.44	2.33	2.34	1.49	1.36	1.51	1.81			5.94	6.95	12.89	510
		P4	685	0.04	0.07	0.07	0.06	0.05	0.07	0.11	0.11			0.27	0.31	0.58	260
9	65.4	P1	93.7	2.1	3.25	4.84	5.7	6.57	5.55	5.88	4.99			19.39	19.49	38.88	1410
		P2	117.6	0.066	1	1.53	1.34	1.13	1.22	2.01	2.57	2.1	2.7	6.84	8.83	15.67	1150
		P3	290.2	0.41	0.38	0.36	0.76	0.66						1.43	1.14	2.57	510
		P4	654.1	0.02	0.05	0.03								0.05	0.05	0.1	250
10	66.9	P1	104.3	1.48	3.73	5.07	5.26	4.52	4.11					11.07	13.1	24.17	1300
		P2	180.5	0.29	0.69	1.56	2.27	2.94	3.15	2.9	2.56			7.69	8.67	16.36	800
		P3	367	0.06	0.19	0.36	0.68	0.75	0.86	0.83	0.85	1.02	1.27	3.02	3.85	6.87	420
		P4'	740.8	0.03	0.04	0.05	0.04							0.08	0.08	0.16	230
11	185.8	P1	246	0.2	0.25	0.26	0.06	0.12	0.32	0.32	0.18			0.9	0.81	1.71	1150
		P2	360	0.03	0.08	0.05	0.01	0.15						0.23	0.09	0.31	820
12	75.8	P1	84.6	1.39	1.99	2.54	2.86	2.28	2.47	2.55	2.1			8.76	9.42	18.18	1690
		P2	155.3	0.05	0.18	0.17	0.23	0.25	0.43	0.42	0.36	0.44		1.33	1.2	2.53	990
		P3	340	0.07	0.05	0.11	0.17	0.19	0.24	0.18	0.19	0.16		0.71	0.65	1.36	490
13	260.5	P1	108	5.65	10.99	8.35	7.69	4.68	3.92					18.68	22.6	41.28	2960
		P2	78.5	0.36	0.47	0.36	0.48	0.81	0.69					1.53	1.64	3.17	3940
		P3	197.9	0.04	0.01									0.04	0.01	0.05	1730
14	112.3	P1	63.7	24.95	3.22	73.78	60.22	20.1	8.99	46.5				165.3	72.43	237.73	2790
		P2	141.7	3.17	10.37	9.12	6.3	9.69	7.33	10.2	6.28	6.05		38.18	30.28	68.46	1370
		P3	330.3	0.58	1.86	2.91	3.37	3.6	2.81	2.8	2.57			9.89	10.61	20.5	640

3.5 Event Results

The following paragraphs discuss the results from each event individually.

3.5.1 Event 1

Triggering of the recording instrumentation was attempted using the pressure signals from each of the transducers. The instrumentation was configured on the basis of predictions for underwater blast in free water for the total explosive quantity detonating simultaneously. Subsequent to the detonation the explosives configuration was determined to be individual shells connected via approximately 0.5 m of detonating cord. This would result in approximately 70 microseconds between the detonation of each shell. Consequently the blast would be less than that for the total quantity of explosives detonating simultaneously. As a consequence the recorders did not trigger. The only result that can be concluded from this event is that the pressure levels did not exceed those quoted in Table 2.

3.5.2 Event 2

The explosives were electrically initiated and the instrumentation triggered using DSTO equipment. Pressure time records were obtained for P1, P3 and P5. Transducer P5 functioned correctly but the signal level obtained was too low to discern impulse but the peak is approximately 1 kPa. The pressure pulses correlated well with the predicted arrival times but the signal amplitudes were significantly smaller than those predicted for open water detonations.

3.5.3 Event 3

The detonation was delayed for over three hours after the high tide and consequently the surrounding water level was lower than that in the "pool" in which the explosives were deployed. This meant that there was no continuous water medium through which the shock wave could propagate hence no pressure records were obtained.

3.5.4 Event 4

This detonation was conducted at the same time as Event 3. The first three pressure transducers on Little Bang Beach were laying on the mud flats exposed to the air at the time of detonation. There was little water cover over the explosives and therefore the shock wave did not propagate along the narrow channel, that still contained water at this stage of the tide, with sufficient magnitude to record any signal at the fourth transducer in Strong Tide Passage.

3.5.5 Event 5

Triggering of the recording instrumentation was attempted using the pressure signals from each of the transducers. The signal levels used were reduced to the point at which some of the recorders were triggering on the electrical noise on the transducer inputs. At the time of detonation the recorder for P5 had already triggered. The others did not trigger so consequently the only results that can be determined from this event are similar to event one, that the pressure signal amplitudes were below the trigger levels set as shown in Table 2.

3.5.6 Event 6

The explosives were initiated using DSTO electrical equipment allowing synchronisation with the data recorders. Records were obtained from all 4 transducers. Although transducer P4 functioned correctly the signal level obtained was too low to discern any meaningful data. Due to the explosives being deployed in Barricade Passage the closest transducer was P2. The results correlate well for arrival times but the peak pressures are well below those predicted for similar detonations in open water.

3.5.7 Event 7

The bomb was deployed on the edge of the boat channel on Big Bang Beach so as the resultant blast could propagate directly from the bomb to the transducers to maximise the blast pressure results. The explosives were electrically initiated and the instrumentation triggered using DSTO equipment. Pressure time records were obtained for P1, P2 and P5 allowing measurements over a range of distance to beyond 1200 m. The pressure pulses correlated well with the predicted arrival times but the signal amplitudes were smaller than those predicted for open water detonations. The amplitudes were closer to predictions than some of the other detonations at the closest transducer but the attenuation due to the shallow water reduced the amplitude significantly for the distant transducers.

3.5.8 Event 8

The two warheads detonated for this event were deployed on the edge of the boat channel on Little Bange Beach again so as the resultant blast could propagate directly from the bomb to the transducers to maximise the blast pressure results. The explosives were electrically initiated and the instrumentation triggered using DSTO equipment. Pressure time records were obtained for all four transducers. The pressure pulses correlated well with the predicted arrival times but the signal amplitudes were smaller than those predicted for open water detonations. The amplitudes were closer to predictions than some of the other detonations at the closest transducer but the attenuation due to the shallow water reduced the amplitude significantly for the distant transducers.

3.5.9 Event 9

The data recorders for this event were triggered manually on hearing the detonation. This was successful but due to using this method arrival times can not be determined. The resulting pressure-time histories have negative time on the time axis because the recorders were configured to stop recording at the trigger signal. Pressure time records were obtained for all four transducers. The pressure signal amplitudes were much smaller than those predicted for open water detonations.

3.5.10 Event 10

The explosives were electrically initiated and the instrumentation triggered using DSTO equipment. Pressure-time histories were obtained for all four transducers. The pressure pulses correlated well with the predicted arrival times but the signal amplitudes were much smaller than those predicted for open water detonations. The explosives for this event were positioned in a hole on Little Bang Beach and were covered with numerous sandbags. This positioning and covering has focussed the blast upwards, due to being in a hole, and attenuated the blast due to the sandbags.

3.5.11 Event 11

The data recorders for this event were triggered manually on hearing the detonation. This was successful, except for P5, but due to using this method arrival times can not be determined. The resulting pressure-time histories have negative time on the time axis because the recorders were configured to stop recording at the trigger signal. Pressure time records were obtained for three transducers. Transducer P3 failed to function and the recorders were manually triggered prior to the shock wave reaching the furthest transducer P5. The explosives for this event were positioned in the "Secondary Boat Channel" on Big Bang Beach. This area is a deep narrow channel and the blast from detonations in this location would be directed upward and to a lesser extent outward along the channel, which is approximately a southerly direction. The pressure-time histories are consequently very much smaller than predictions for detonations in open water.

3.5.12 Event 12

The data recorders for this event were triggered manually on hearing the detonation. This was successful but due to using this method arrival times can not be determined. The resulting pressure-time histories have negative time on the time axis because the recorders were configured to stop recording at the trigger signal. Pressure time records were obtained for three transducers. The amplitude of the signals is again significantly smaller than predictions for deep-water detonations.

3.5.13 Event 13

The data recorders for this event were triggered manually on hearing the detonation. This was successful but due to using this method arrival times can not be determined. The resulting pressure-time histories have negative time on the time axis because the recorders were configured to stop recording at the trigger signal. Pressure time records were obtained for three transducers. Due to the explosives being deployed in Barricade Passage the closest transducer was P2. The amplitude of the signals is an order of magnitude smaller than predictions for deep-water detonations.

3.5.14 Event 14

The bomb detonated for this event was deployed in the boat channel on Little Bang Beach. The bomb was electrically initiated and the instrumentation triggered using DSTO equipment. Pressure time records were obtained for three transducers. Transducer P4 operated correctly but there was no discernible pressure signal above the electrical signal noise. The pressure pulses correlated well with the predicted arrival times but the signal amplitudes were smaller than those predicted for open water detonations. The amplitudes were closer to predictions than some of the other detonations at the closest transducer but the attenuation due to the shallow water reduced the amplitude significantly for the distant transducers.

4. Discussion

This experiment was conducted on an opportunity basis and therefore not planned to best suit the needs of analysis of underwater blast parameters. Each event had different explosive composition, explosives mass, explosive casing, distances to the pressure transducers, water depths, seabed structure around the explosives, and containment of the explosives. Most of the detonations contained numerous explosive items that were connected by lengths of detonating cord and as a consequence the entire explosive mass was not detonated simultaneously for these events.

As a consequence of the variability of the detonations and the numerous parameters associated with them it is not possible to reduce the data obtained to determine scaling factors, specifically for this area, with which blast parameters could be predicted accurately for future detonations.

It is possible however to compare the results obtained with well-established predictions for deep-water detonations for each event recorded individually. These comparisons do indicate effects of changing some of the parameters of the detonations.

The plots of the Peak Pressure v Distance, from the explosive charges, are shown in Appendix B and the plots of Impulse v Distance are shown in Appendix C:

It is evident from the plots of Peak Pressure that the shock wave cannot propagate through shallow water as it does in deep water and as a consequence peak levels are reduced. It is worth noting that some events (events 2, 7, 14 and to some extent 8) the peak pressure from the closest transducer, although still smaller than predicted, is of significant amplitude. For these events the explosives were deployed on the mud flats or on ridges at the edge of the boat channels and the blast shock wave could propagate horizontally through the water. In contrast, for most of the events the explosives were deployed in channels or holes and hence the shock wave had to traverse a mound or ridge before propagating through the water. Explosives deployed in Barricade Passage or the Secondary Boat Channel on Big Bang Beach were further contained by the geometry of the surroundings to further absorb energy. Barricade Passage is shown in Figure 4, and Secondary Boat Channel is shown in Figure 5 and Figure 6.

The peak pressures recorded for these events are markedly less than the predictions for deep water.

Figure 4 Barricade passage at low tide

Figure 5 Secondary Boat Channel at low tide; looking down from side of channel.

Figure 6 Secondary Boat Channel at low tide; from seaward.

The impulse results plotted in Appendix C:, remembering that these are the accumulated impulses, and noting that the graphs have a logarithmic impulse scale are significantly less than the predictions for every result. This is to be expected as the reflections from the complex seabed and rock ledges, together with the rarefractions from the sea surface will disrupt the blast shock wave significantly. The graphs have a "threshold" drawn at the 34 Pa.s impulse level as that level at which "no injuries" should occur for mammals diving beneath the water surface [2].

The only events where impulses greater than this threshold were measured were the four events discussed in the paragraph above. For these events the accumulated impulse was greater than the threshold level for varying distances. Event 7 exhibits impulse above the threshold level to a distance of nearly 1000 m from the explosives. Event 7 was the detonation of a Mk 82 bomb positioned on the western ridge of the boat channel on Big Bang Beach. The bomb was positioned further from Big Bang Beach than any other explosive during this exercise, some 150 m from the high water mark. This was at the request of the DSTO personnel to enable the measurement of a shock wave with little interference of the surrounding geography. This placed the bomb clear of the rocky point on the western end of Big Bang Beach with considerably more water over the bomb than other explosives during this exercise. The other events where impulses were measured above the threshold also had the explosives deployed in the open as opposed to in holes and channels.

The amplitude of the impulse for every event reduces with distance at a greater rate than the predictions for deep water. This is further evidence that the shallow water disrupts the blast shock wave as it propagates through the water.

The events with the greatest explosive quantities, Events 11 and 13, did not produce the greatest peak pressures or impulse. These two events were positioned in the Secondary Boat Channel and in Barricade Passage respectively; both locations provide containment of the blast and focus the shock upward to the water surface.

It appears that the normal mode of operation for the Clearance Diver training at Triangular Island provides the best attenuation of blast by placing munitions in deep holes and channels. In addition the separation of explosive items and the connection of them by detonating cord broadens the time over which the detonation occurs and limits the shock wave produced. The limit on the size of munitions used to Mk 82 bombs would also assist in limiting the blast effects to the surrounding environment.

From the available evidence it appears that the clearance diver training conducted at Triangular Island would not generate underwater blast shock waves of significant amplitude to be injurious to mammals at distances greater than 1 kilometre. The greatest pressure levels recorded were from events contrived to produce maximum pressure transmission. When following normal procedures the safe distance would be much less than 1 km.

5. Recommendations

The practise of deploying explosives in the natural and man-made channels and holes on Triangular Island is recommended.

It is not possible to recommend maximum explosive limits on the evidence produced from this exercise but explosives quantities used during the November 1999 exercise as reported produced no significant pressure levels at distances over 1 km. When following normal procedures the safe distance would be much less than 1 km.

6. Acknowledgments

The authors wish to thank the Officers and personnel from the RAN Dive School, HMAS Penguin for their willingness to assist the DSTO personnel and provide advice and details of their operations throughout this exercise.

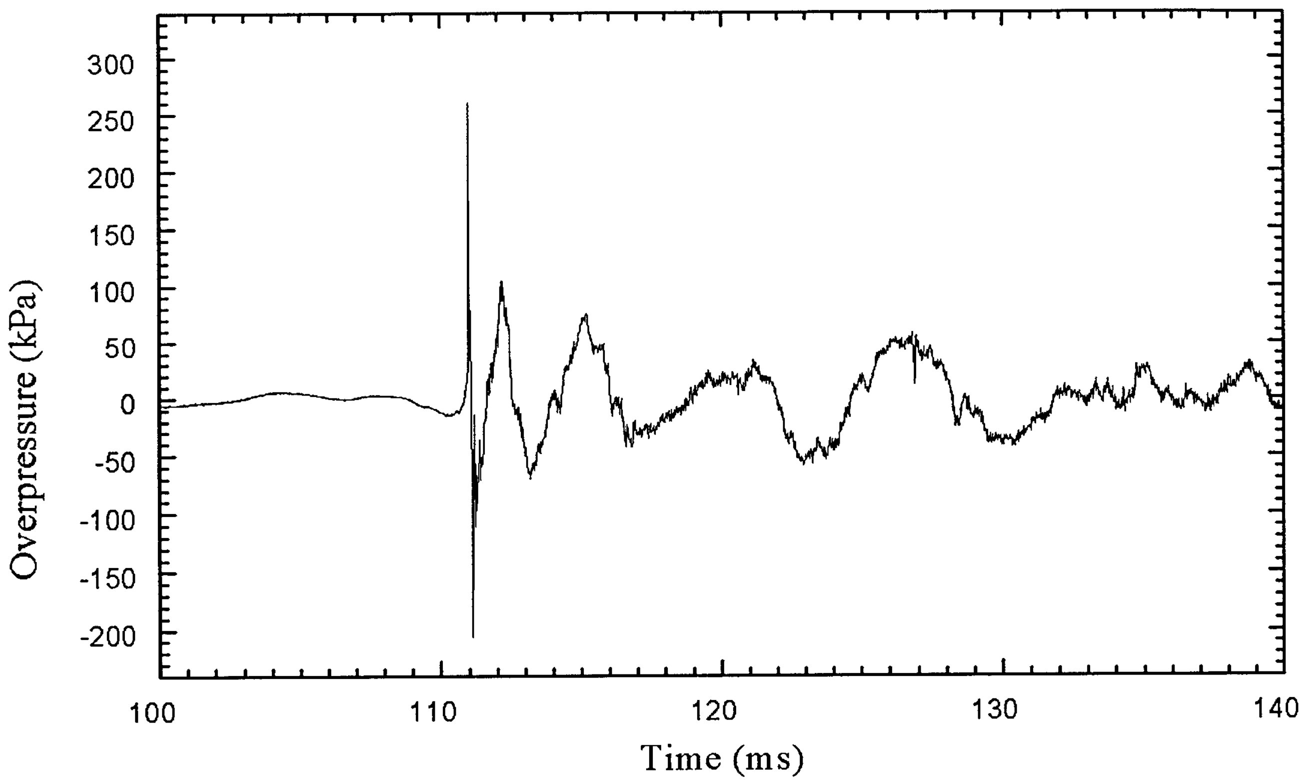
7. References

1. Swisdak, Michael M. Jr (1978) Explosion Effects and Properties: Part II – Explosion Effects in Water Technical Report NSWC/WOL TR 76-116 Naval Surface Weapons Centre, Dahlgren, Virginia, USA.

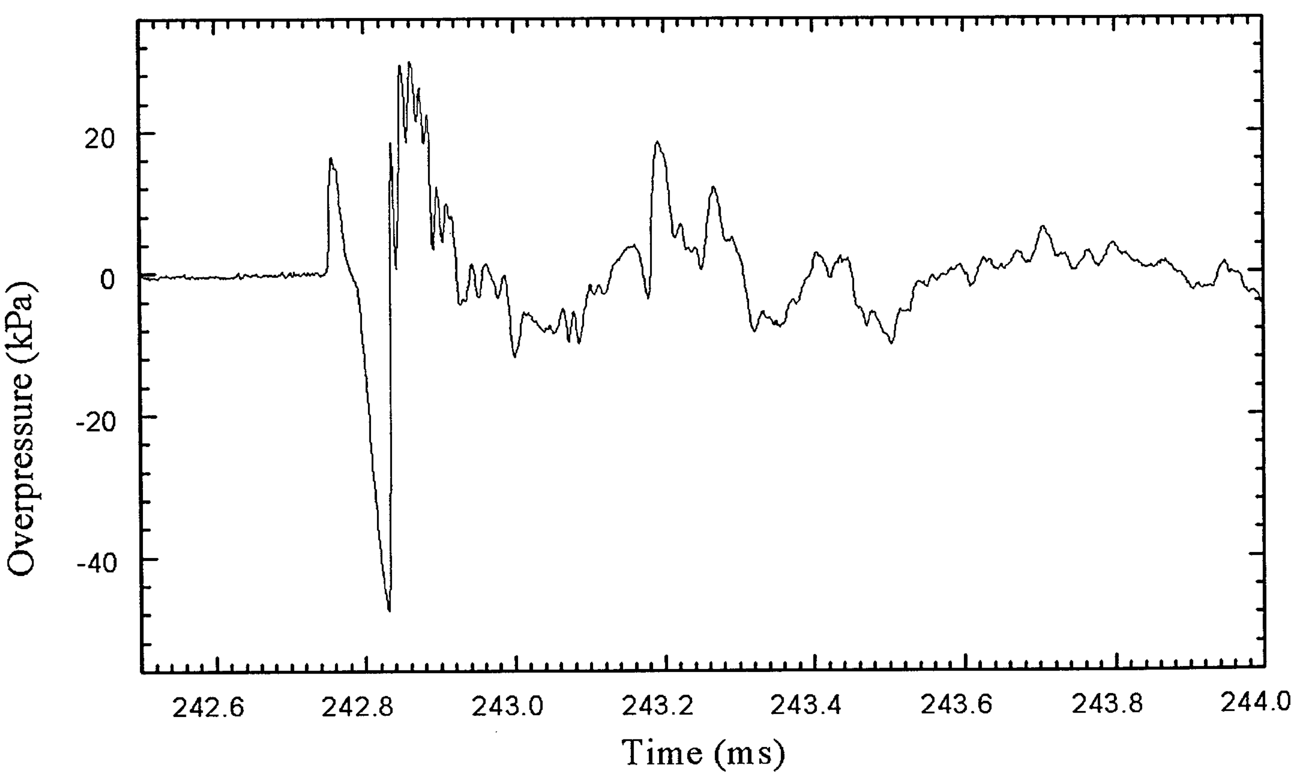
2. Lewis, John. A. (1996) Effects of Underwater Explosions on Life in the Sea. General Document DSTO-GD-0080, Aeronautical & Maritime Research Laboratory, Melbourne

Appendix A: Pressure-Time Histories

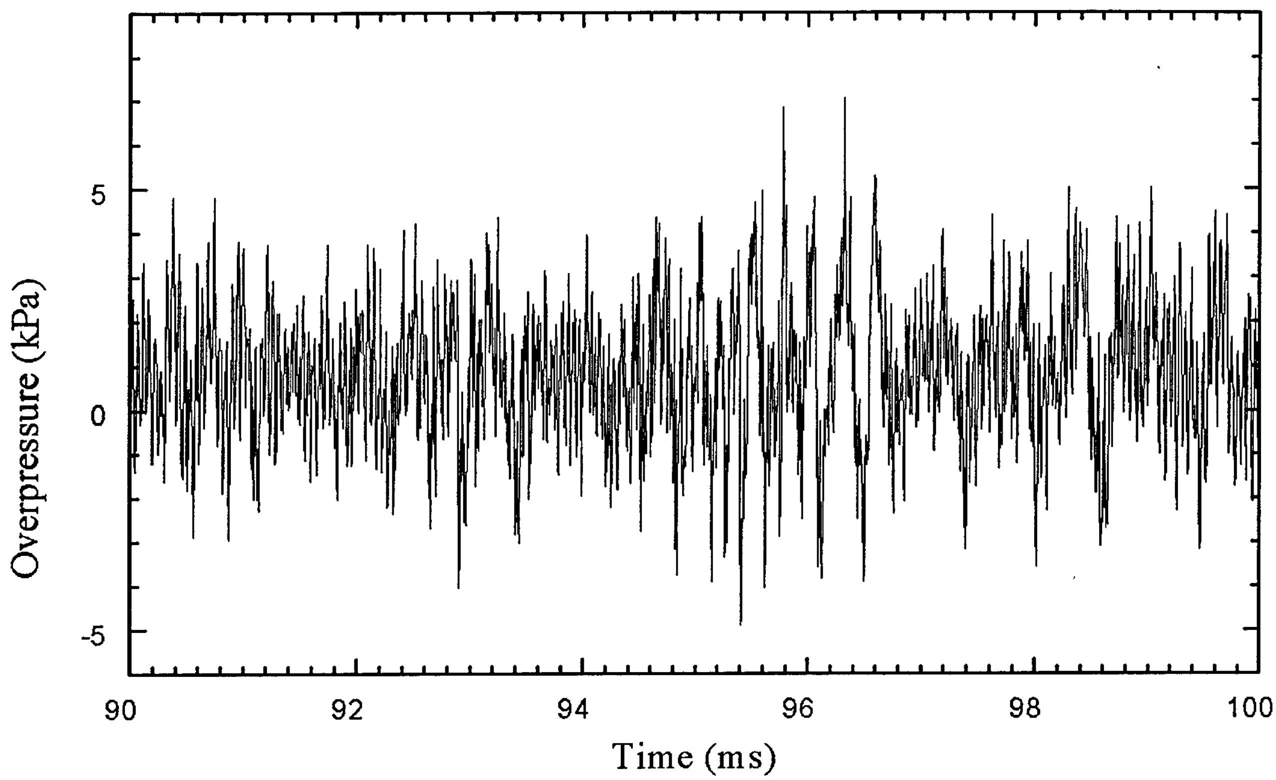
Event No. 2 Transducer P1



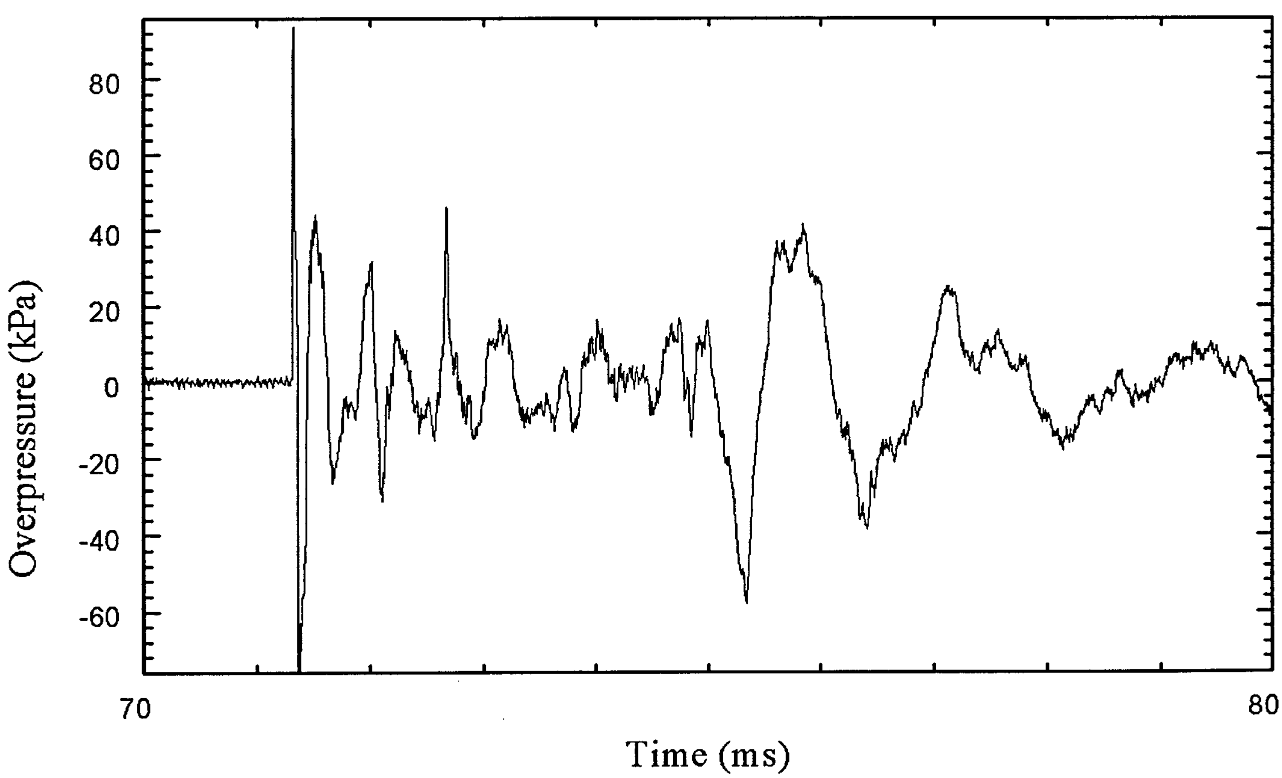
Event No. 2 Transducer P3



Event No. 6 Transducer P1



Event No. 6 Transducer P2



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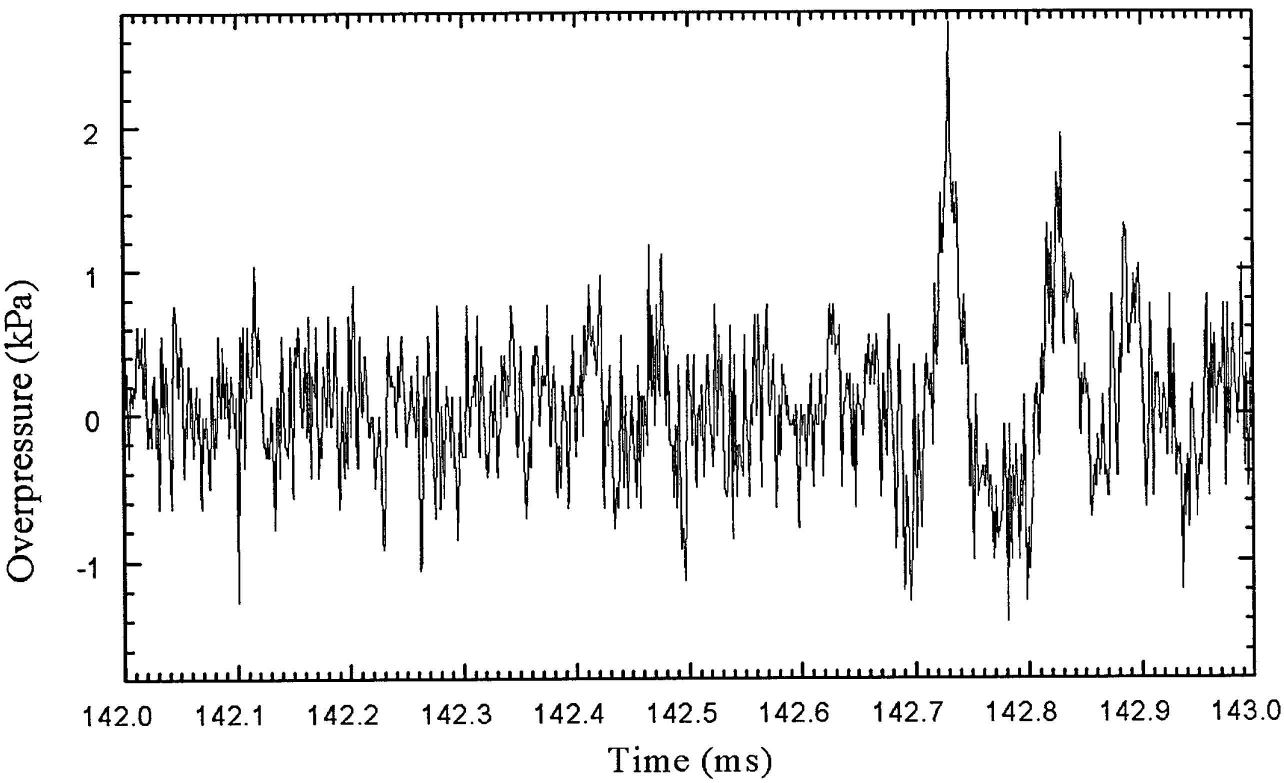
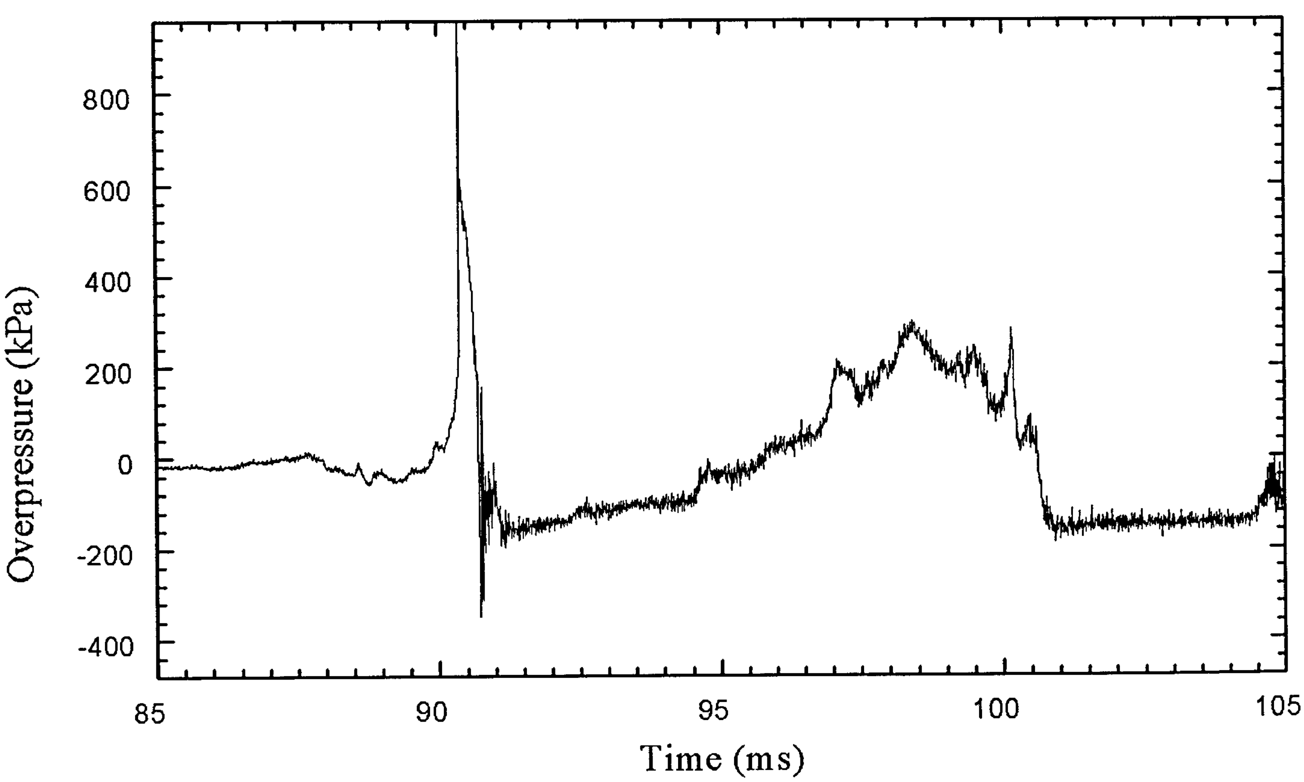


Event No. 7 Transducer P1



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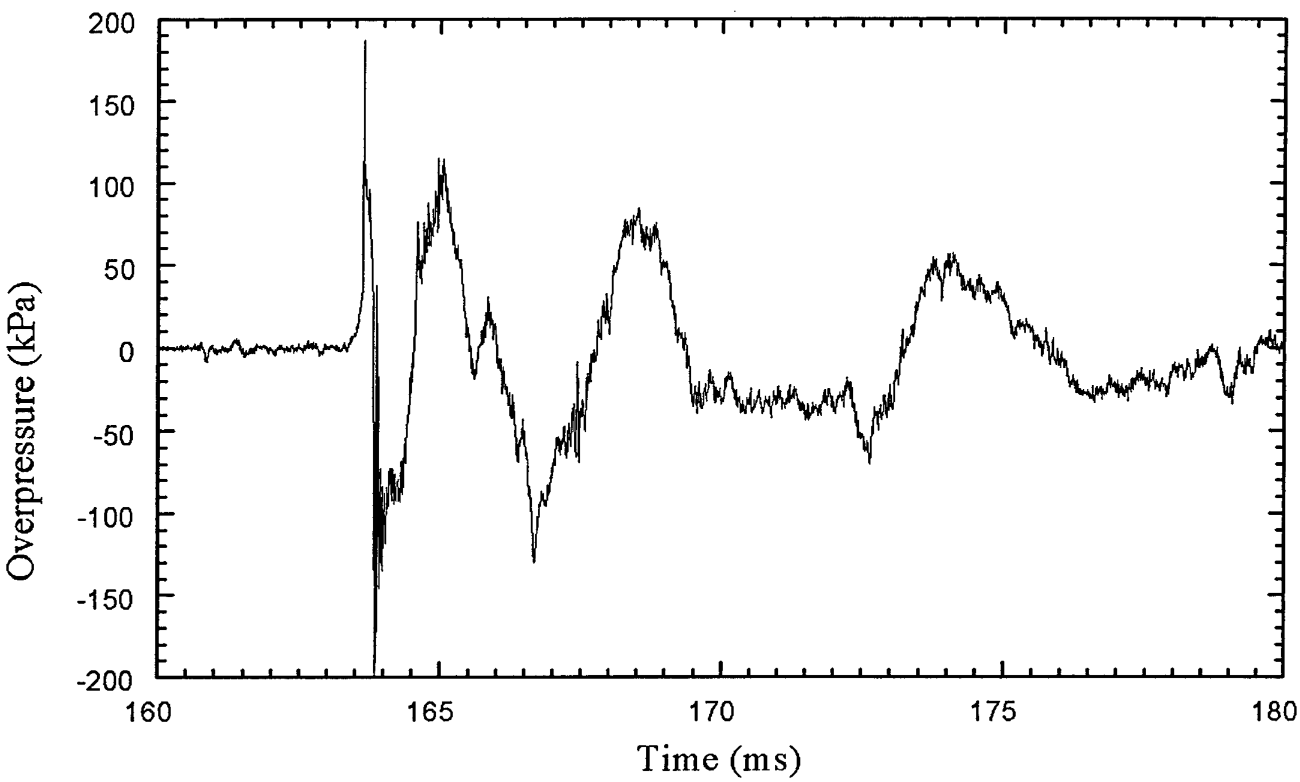
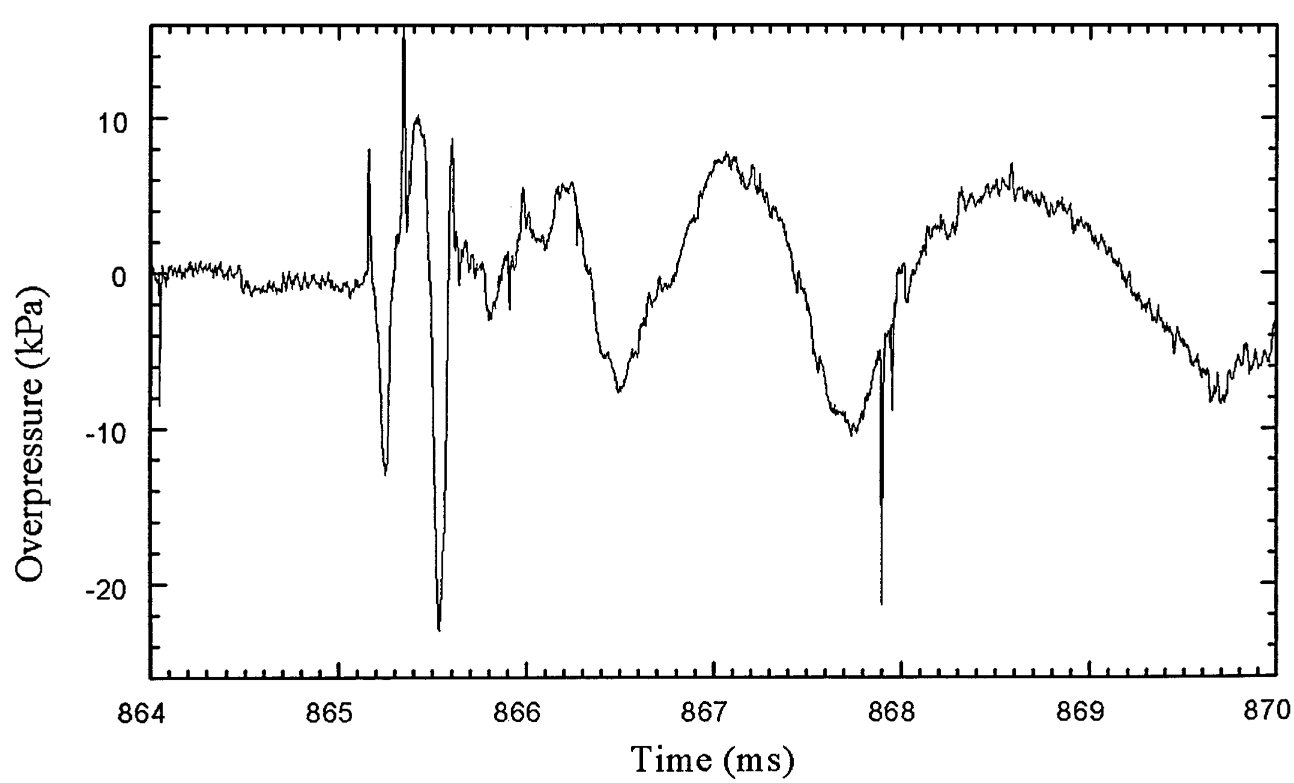
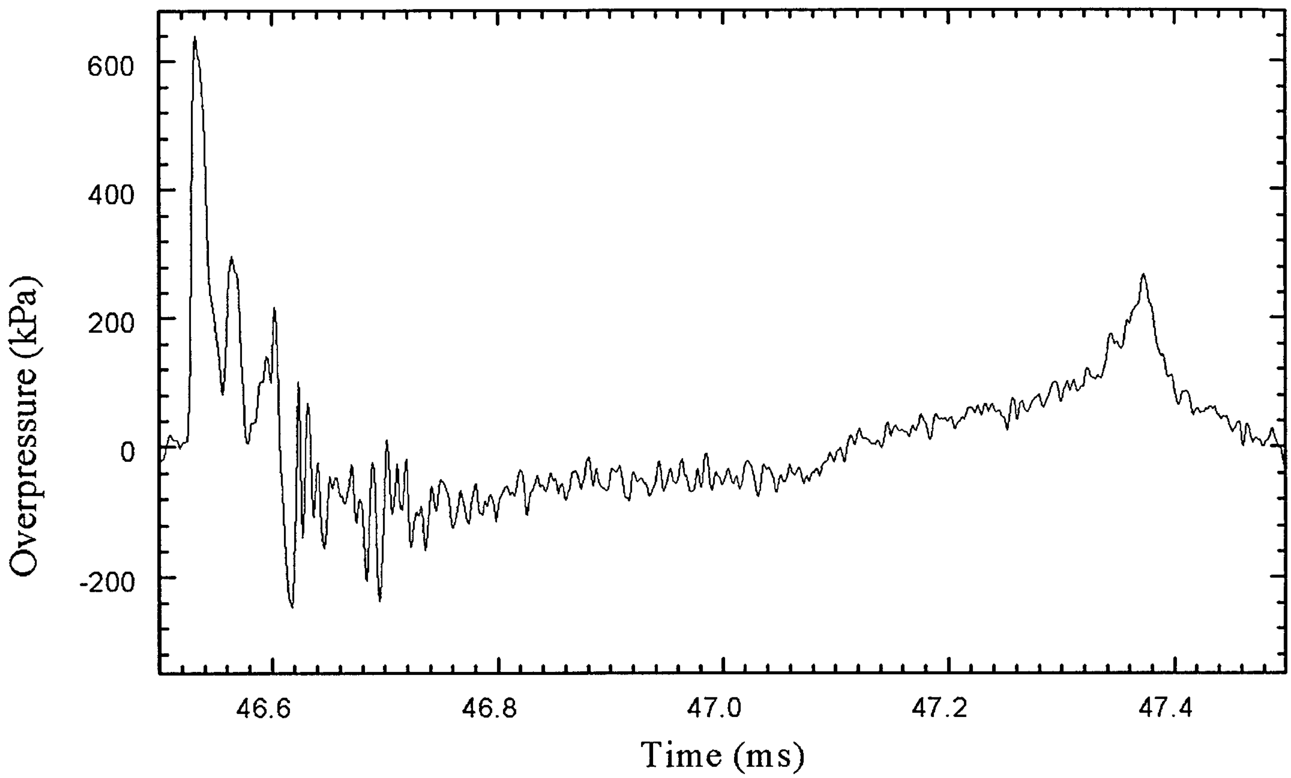


Event No. 7 Transducer P5



Event No. 8 Transducer P1



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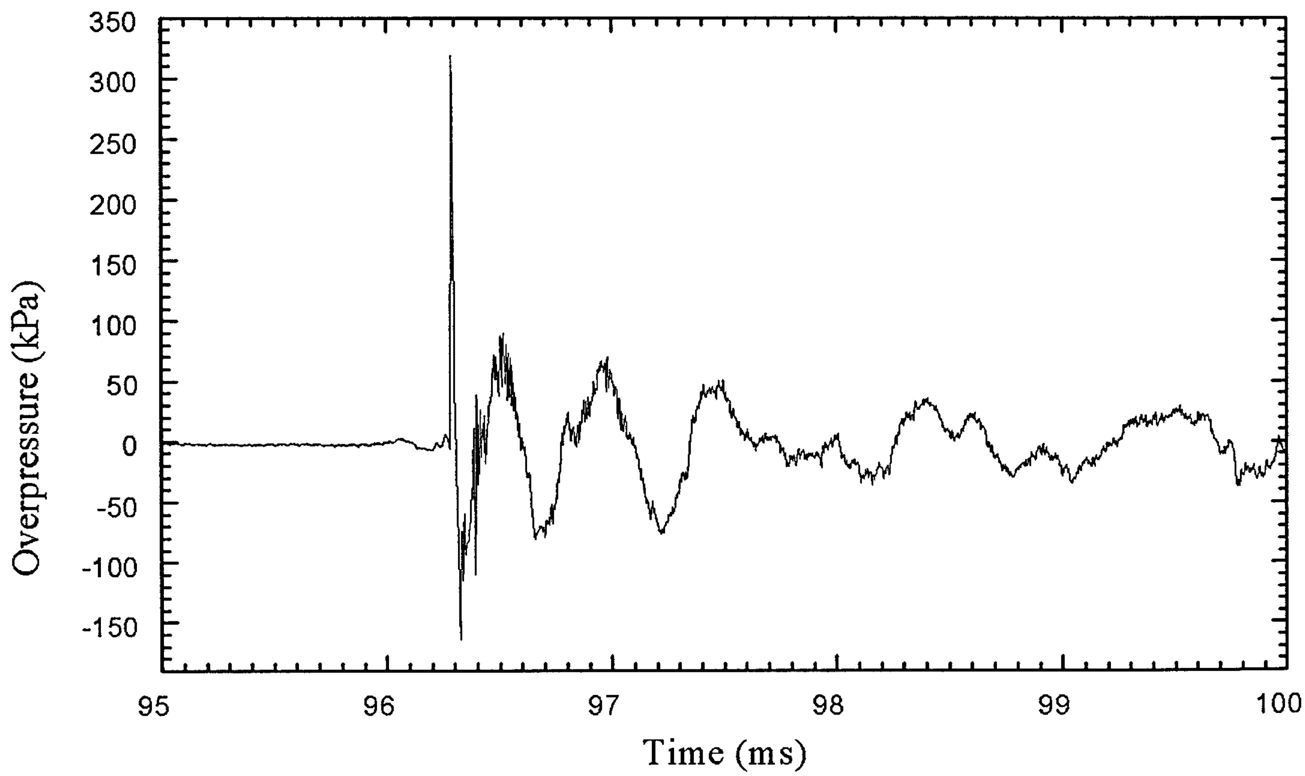

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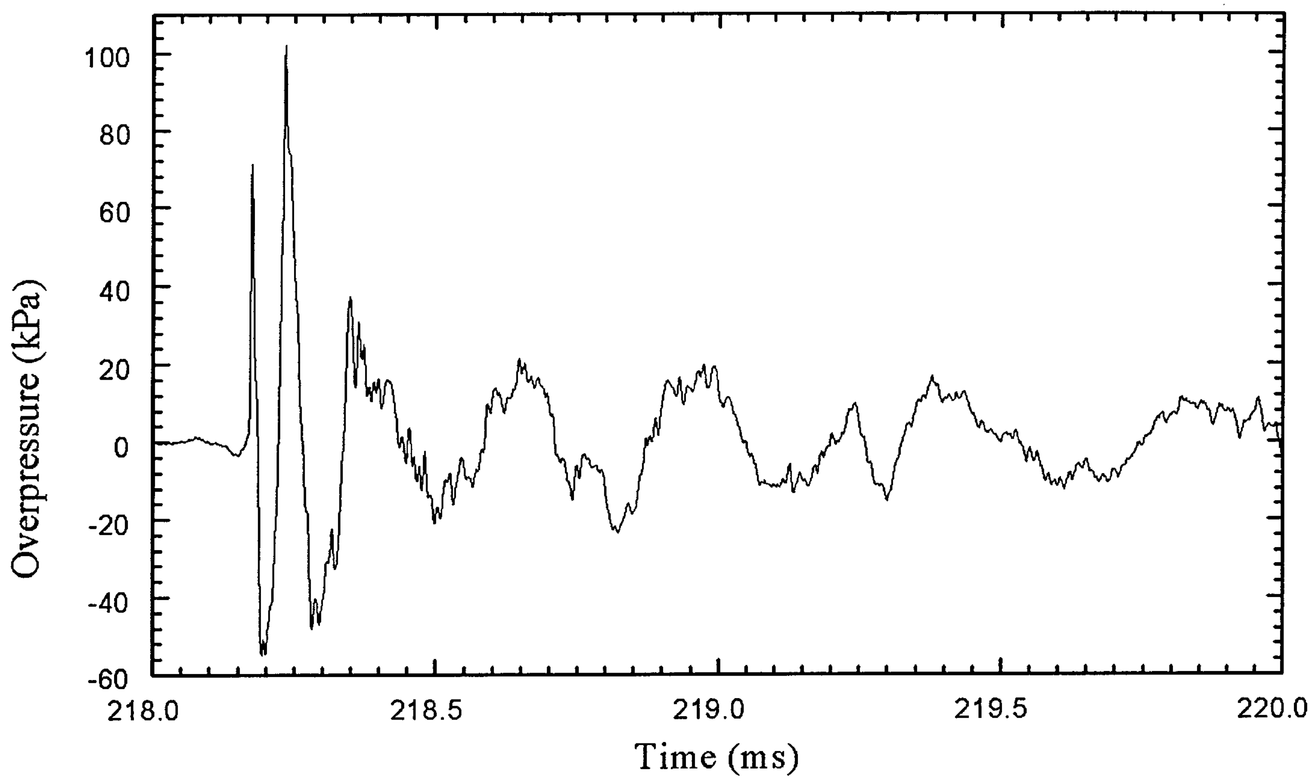
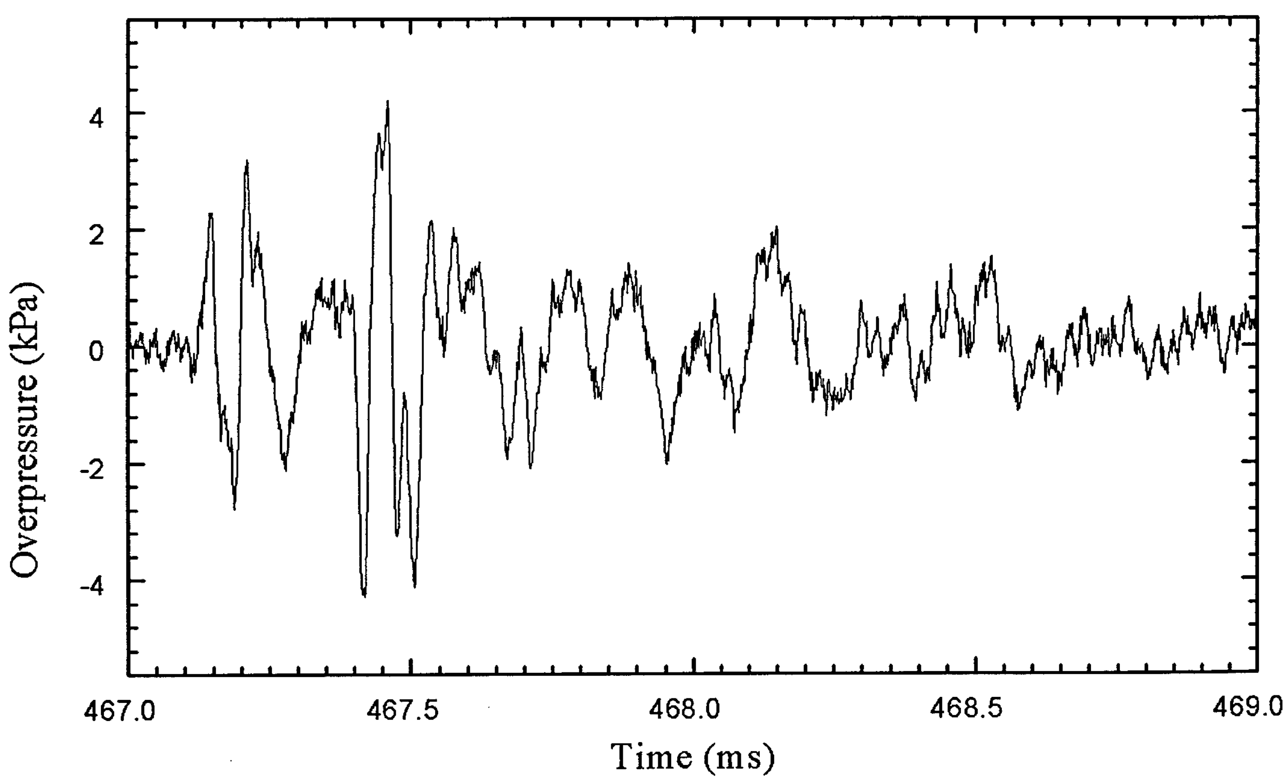
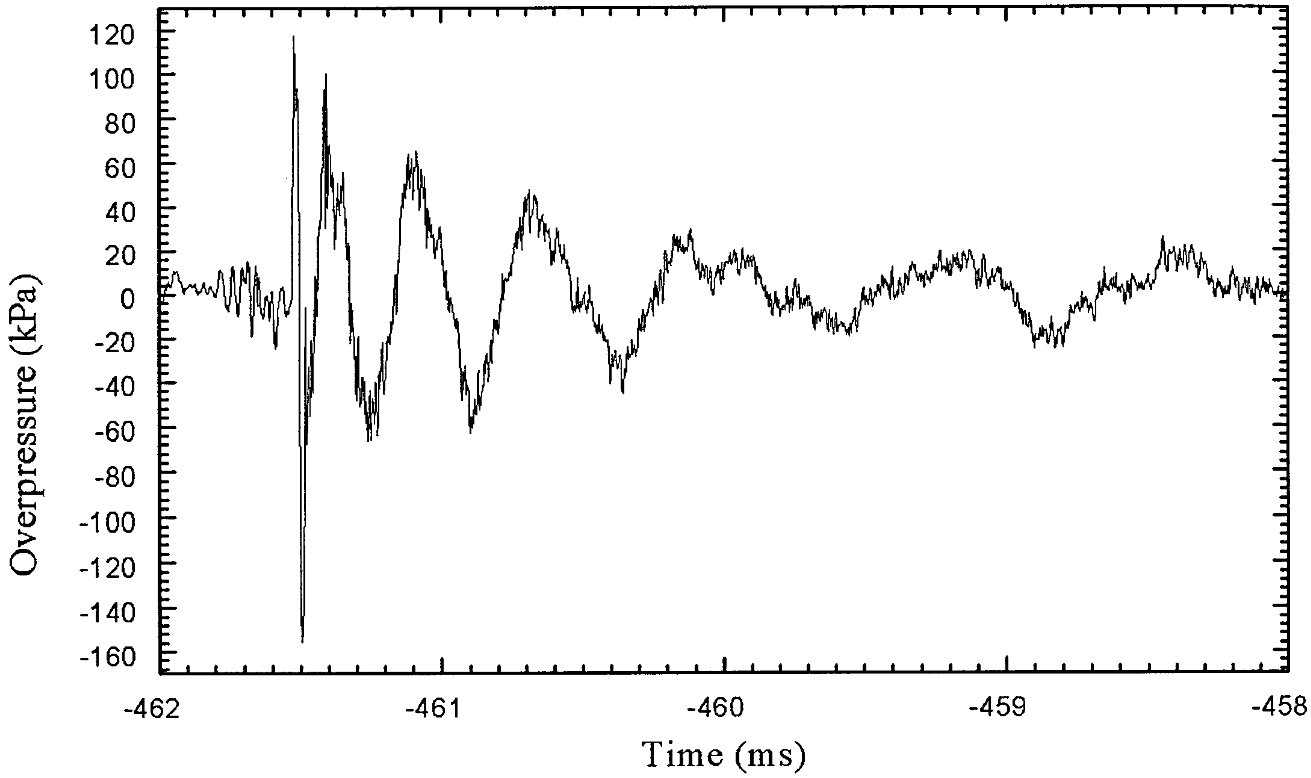


Event No. 8 Transducer P4



Event No. 9 Transducer P1



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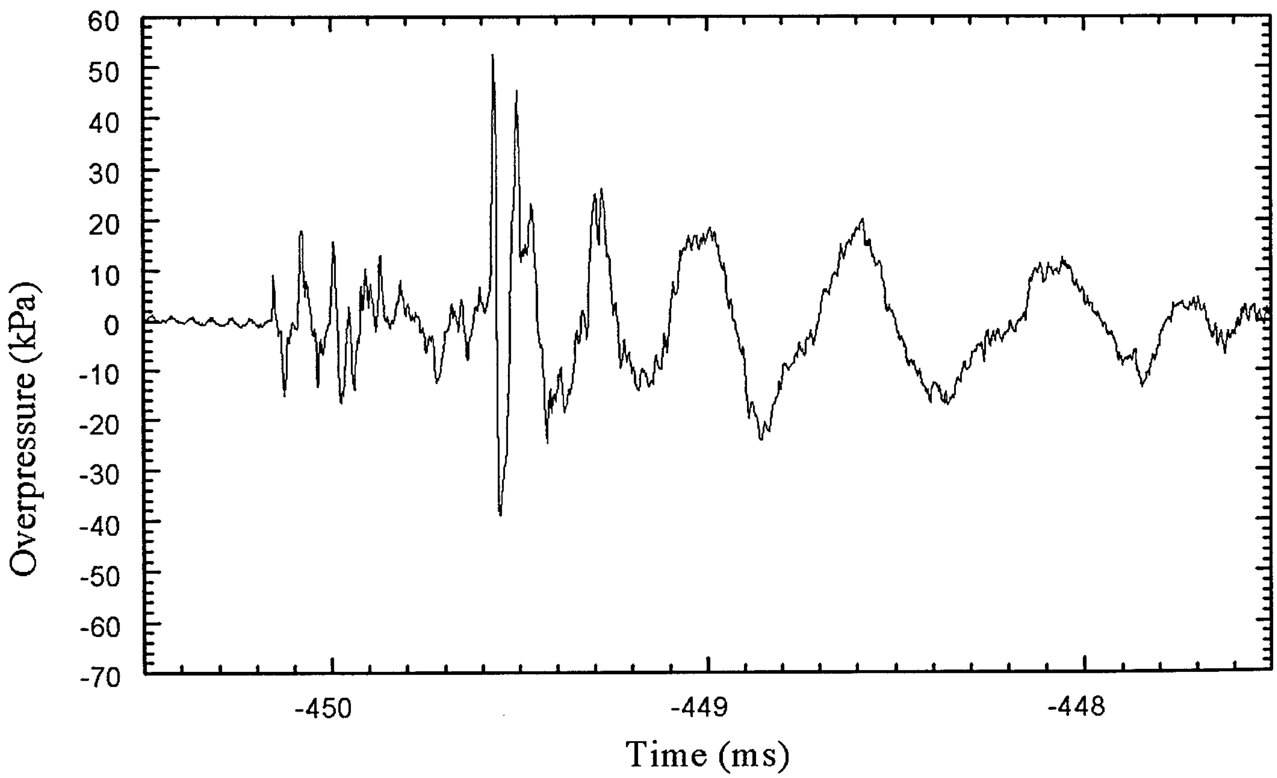

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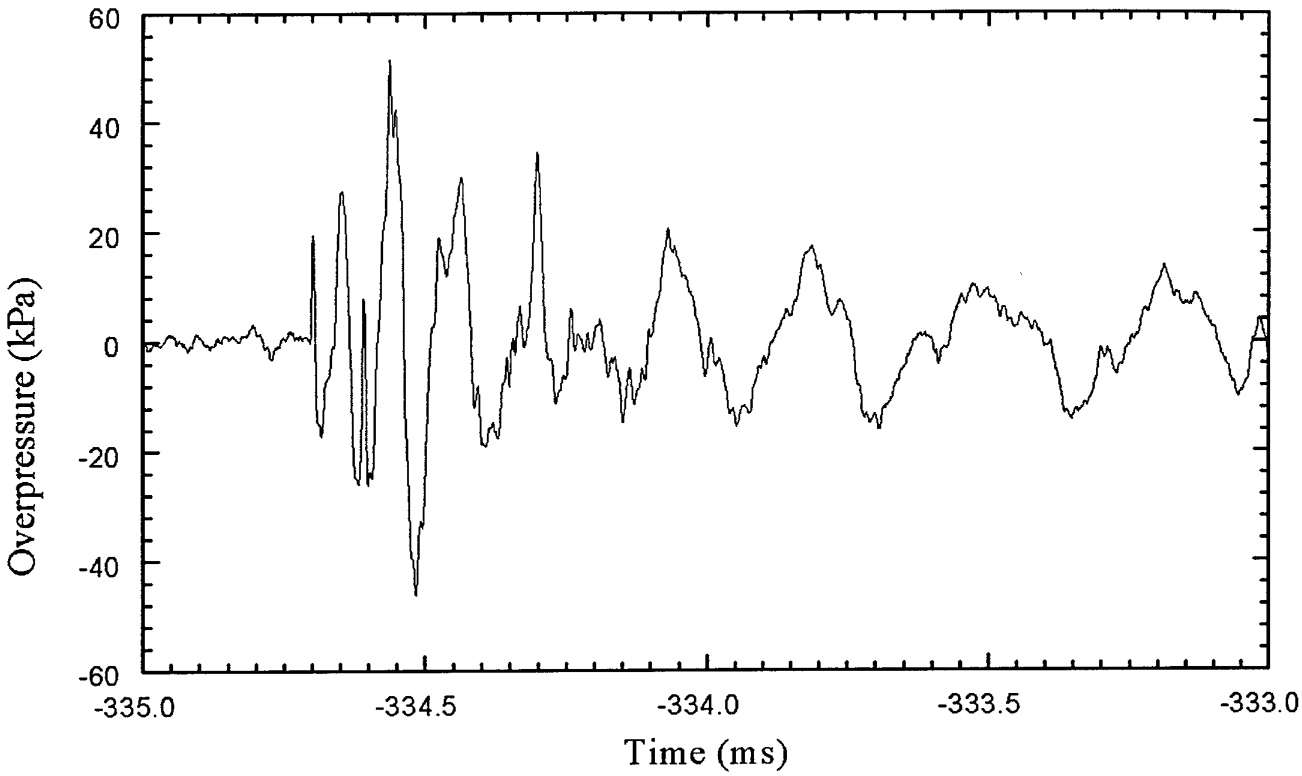

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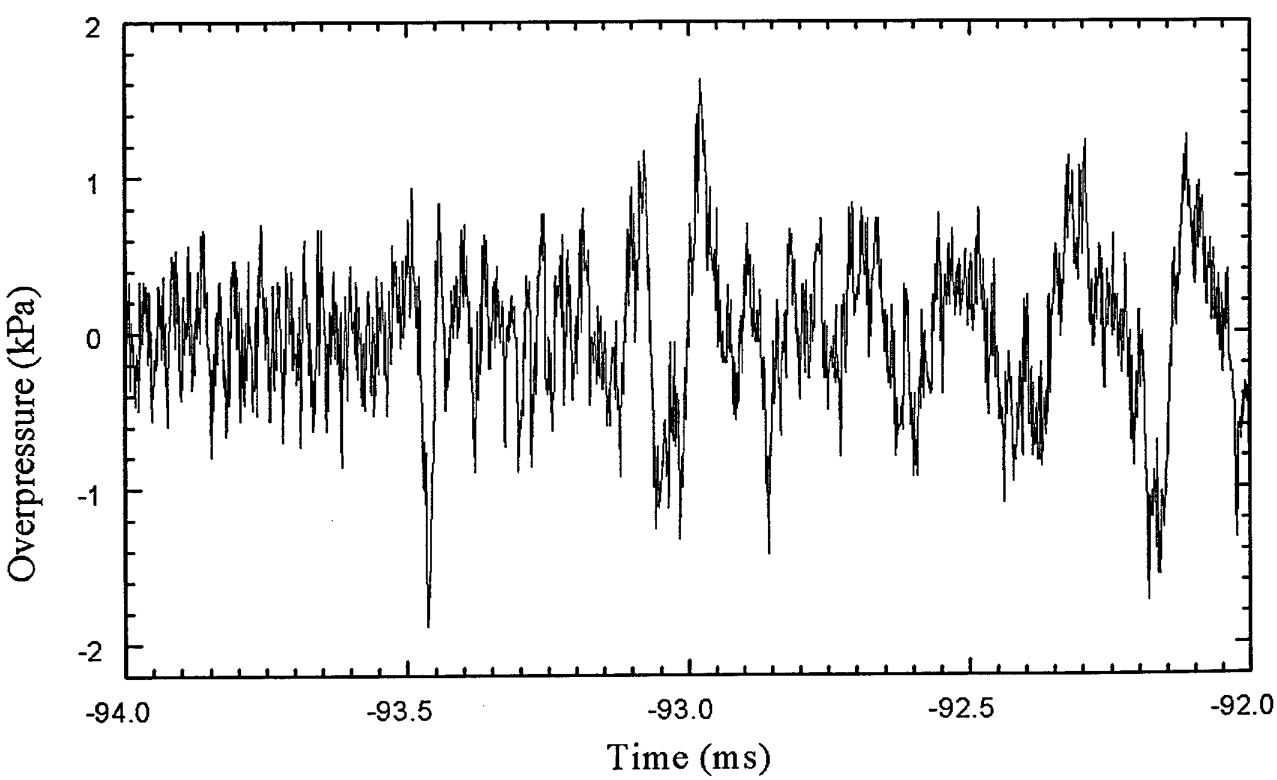
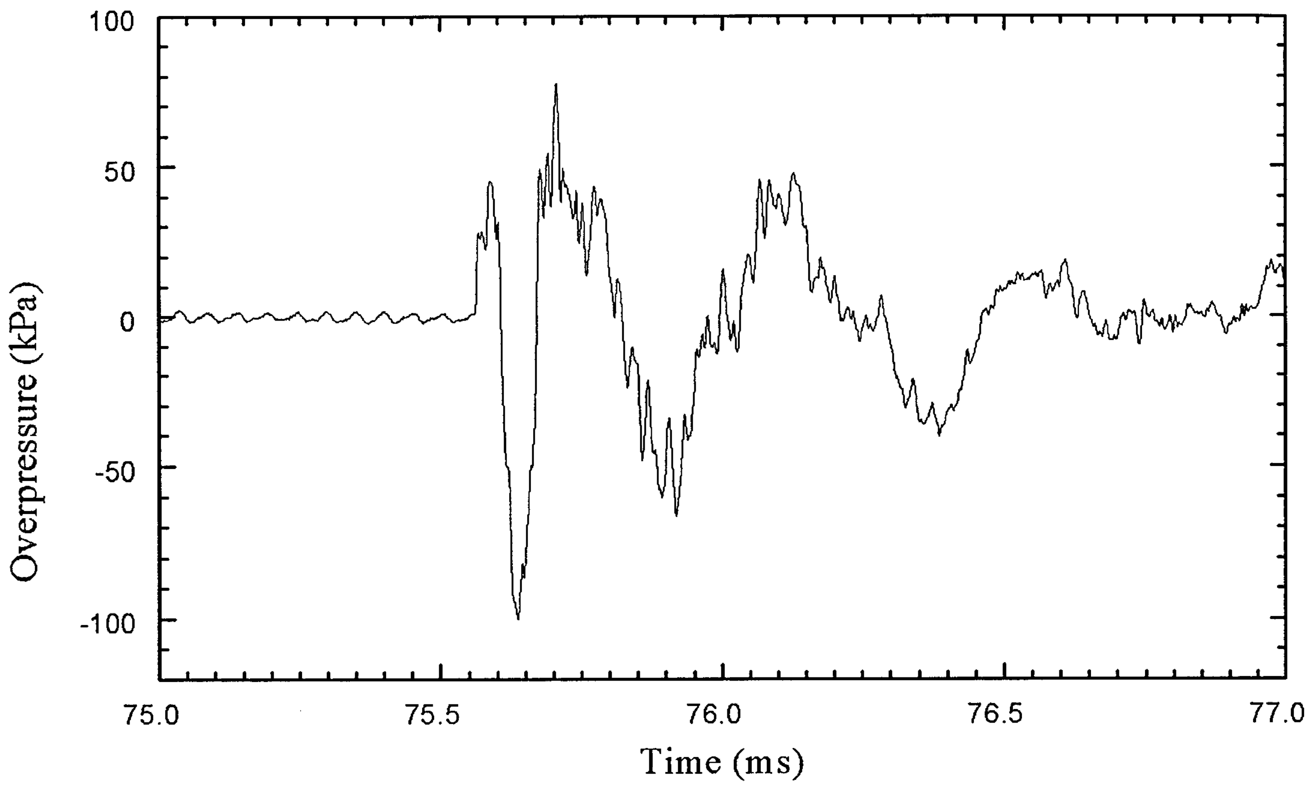


Event No. 10 Transducer P1



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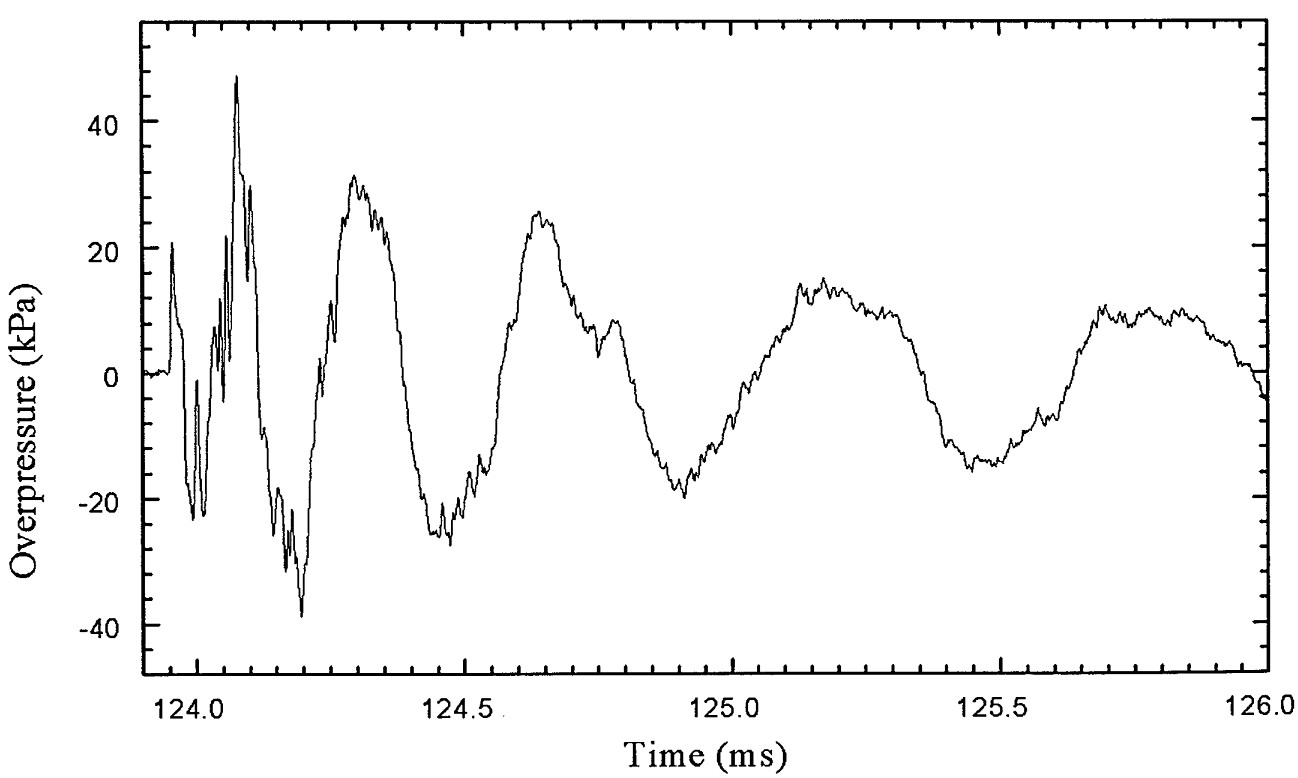

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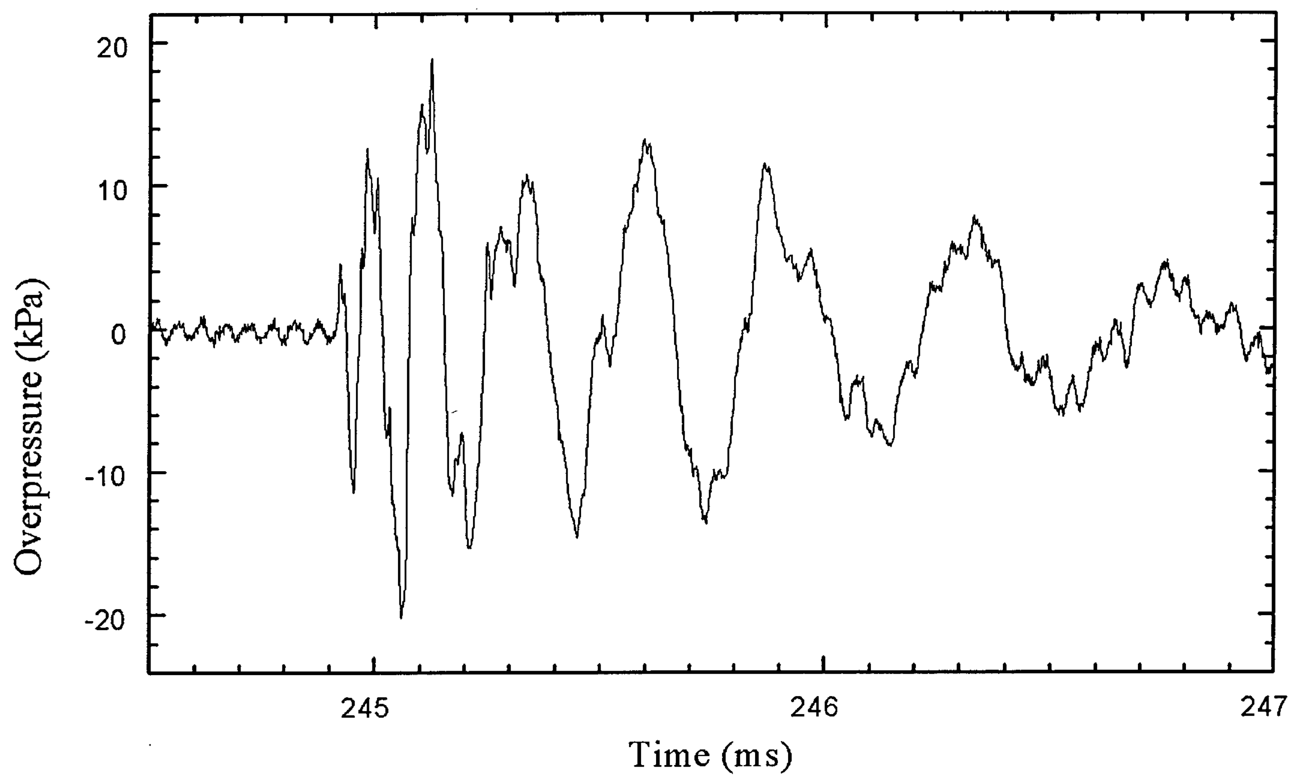
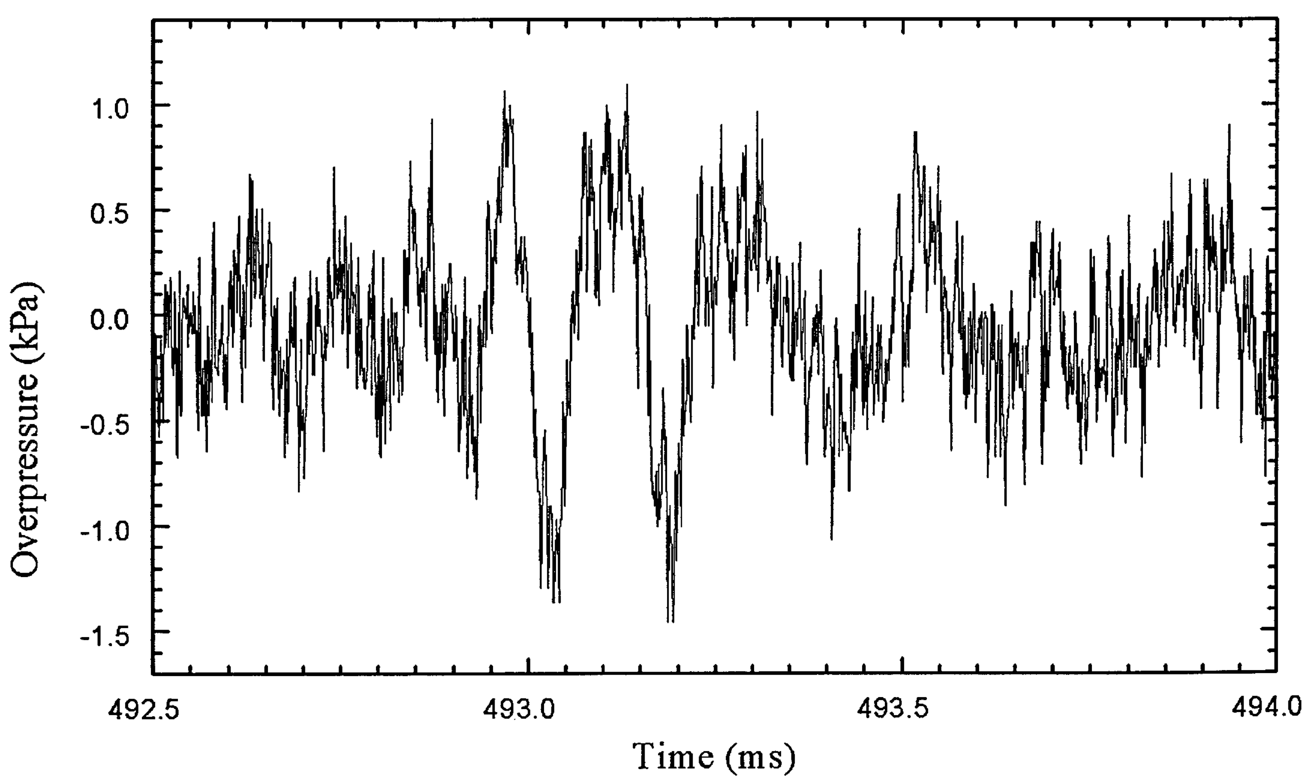
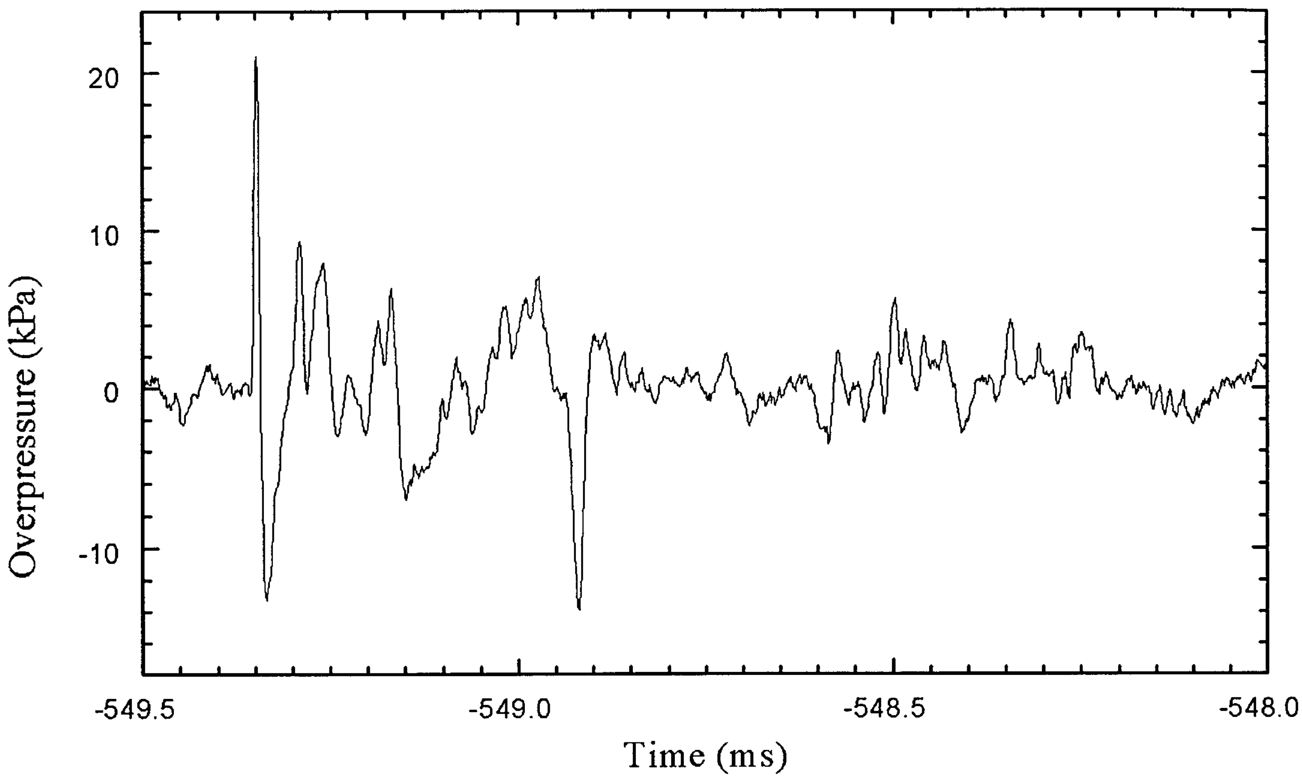


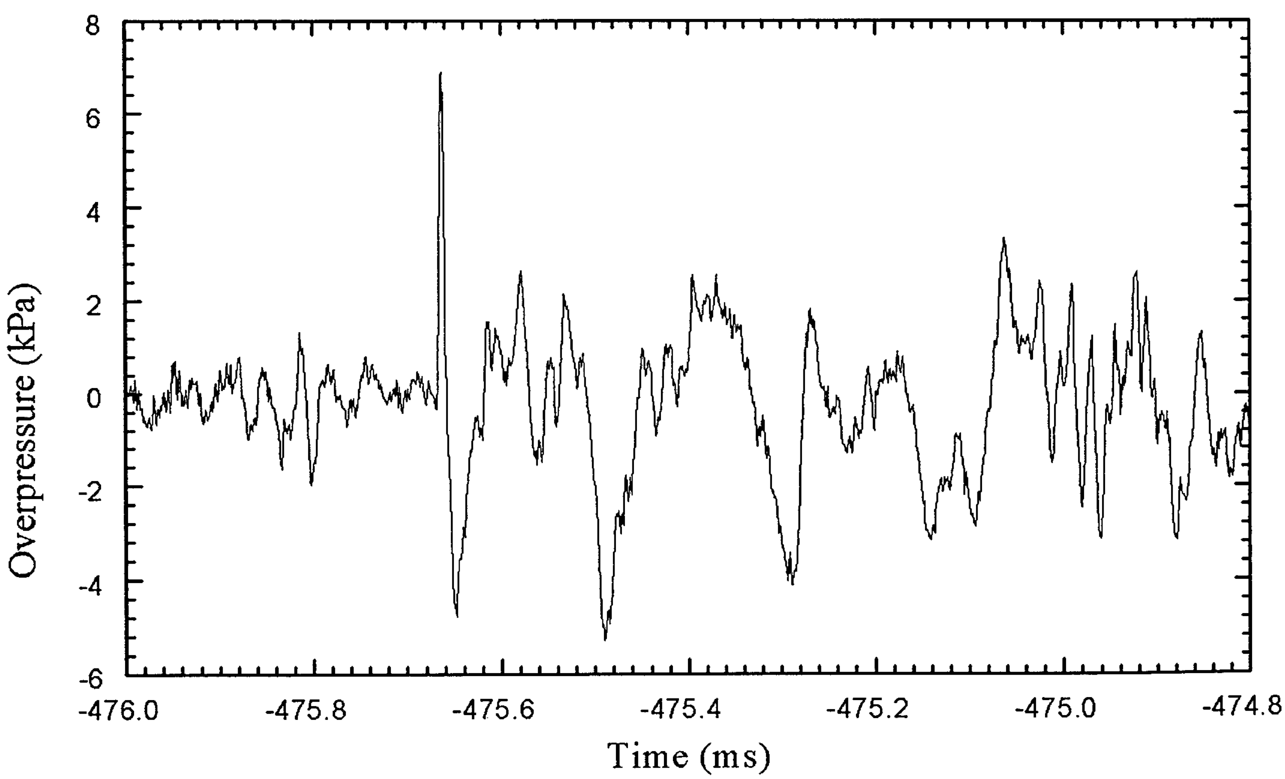
Event No. 10 Transducer P4



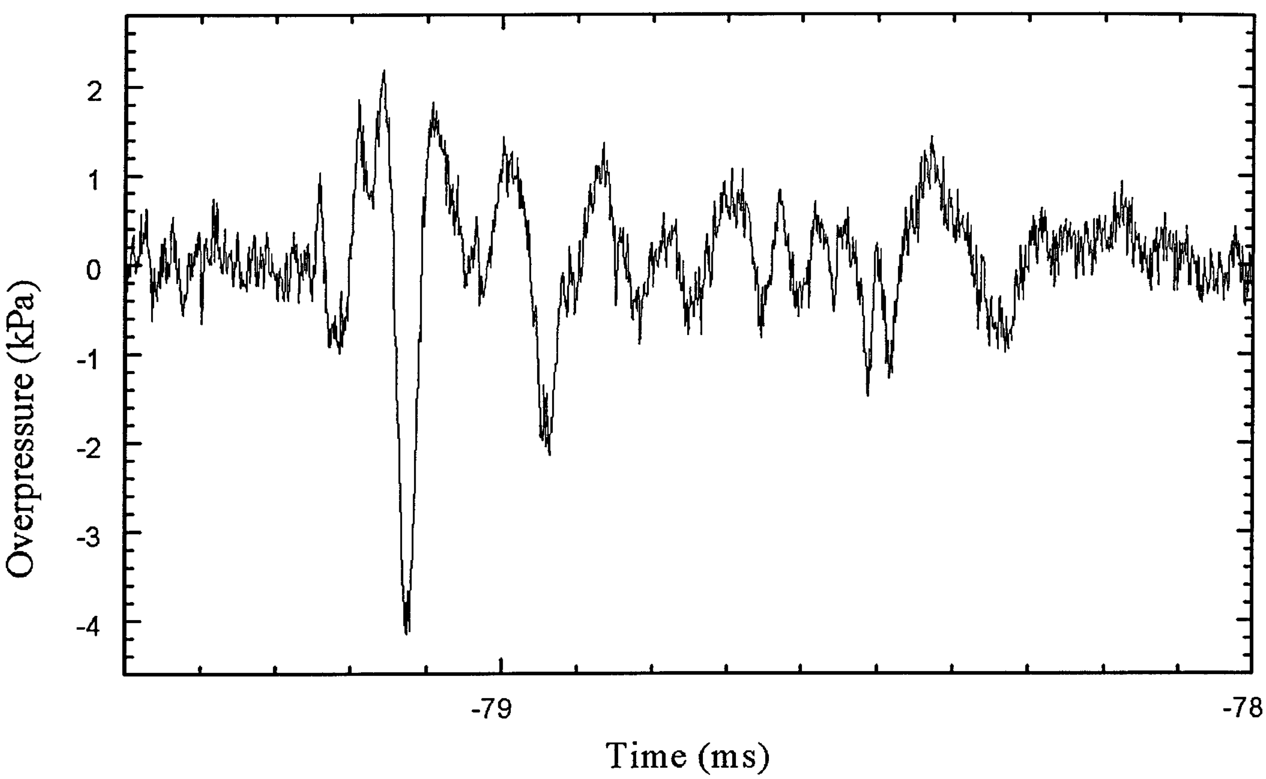
Event No. 11 Transducer P1



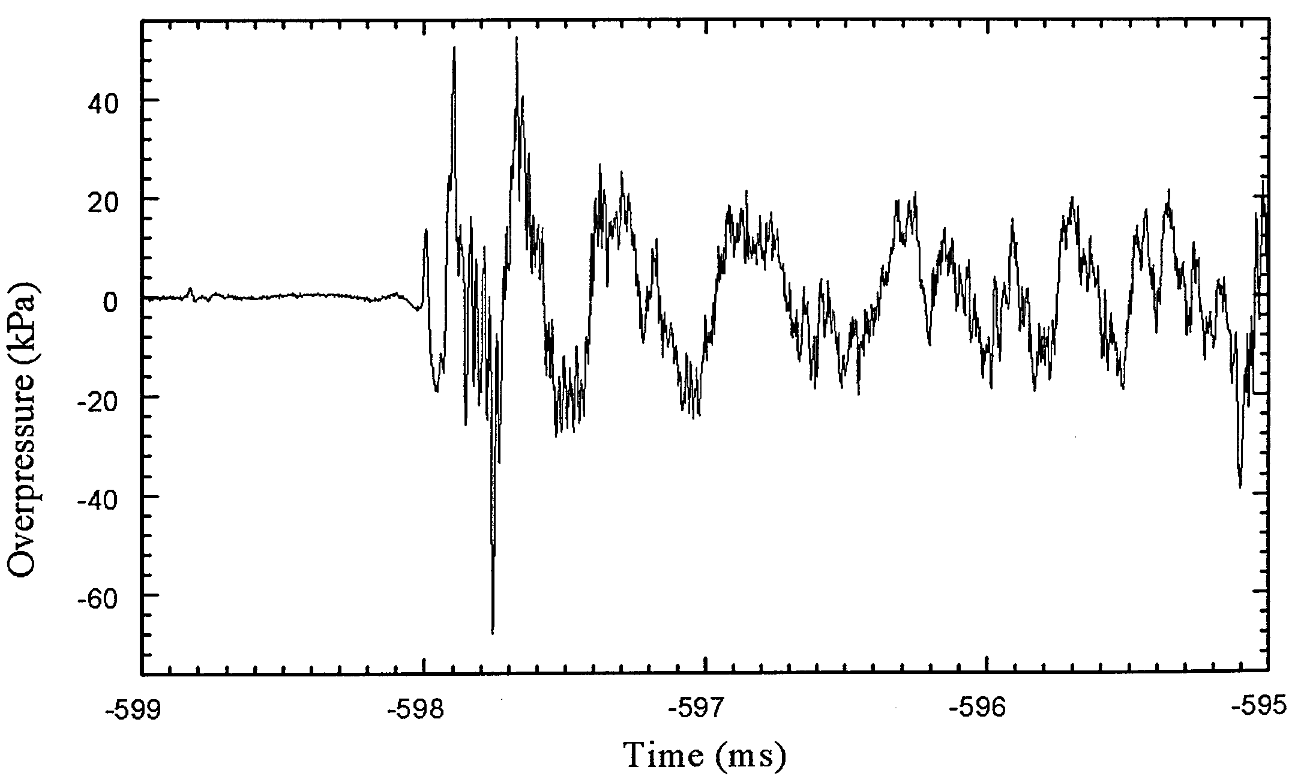
Event No. 11 Transducer P2



Event No. 11 Transducer P4



Event No. 12 Transducer P1



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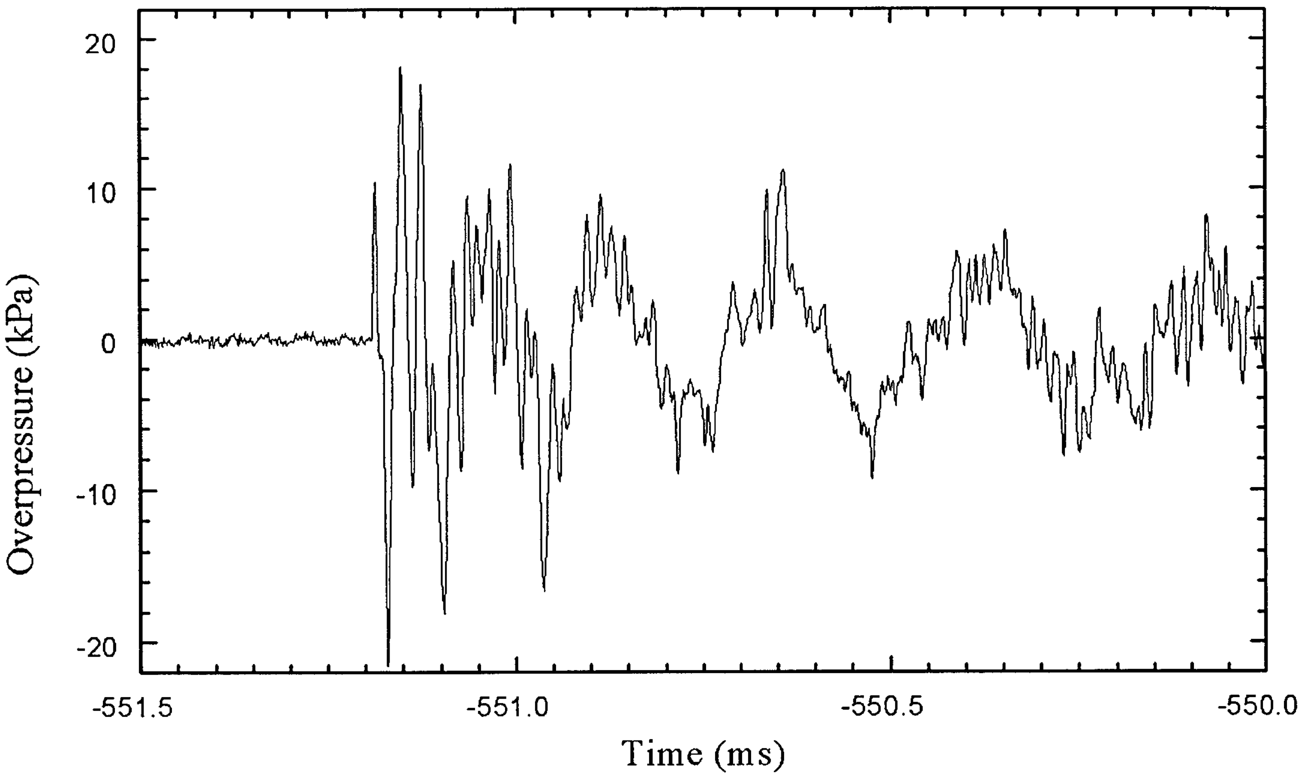

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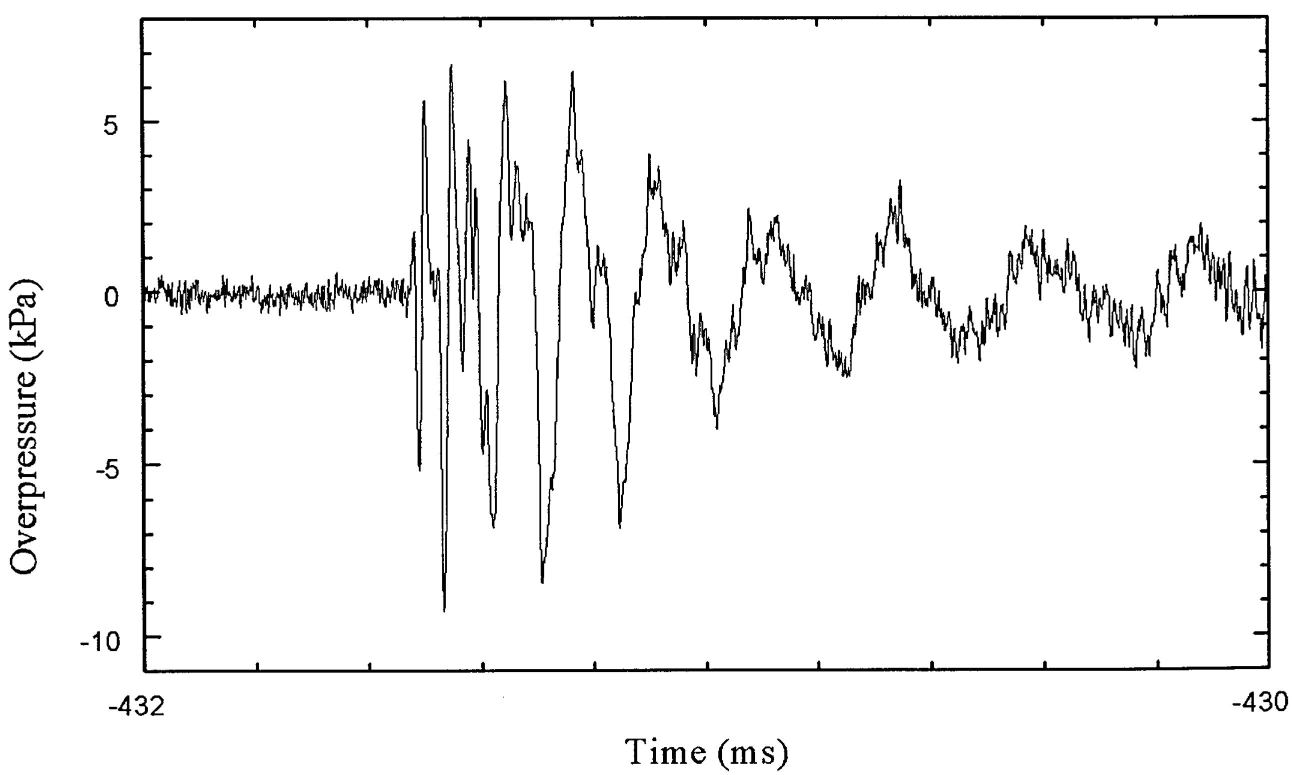

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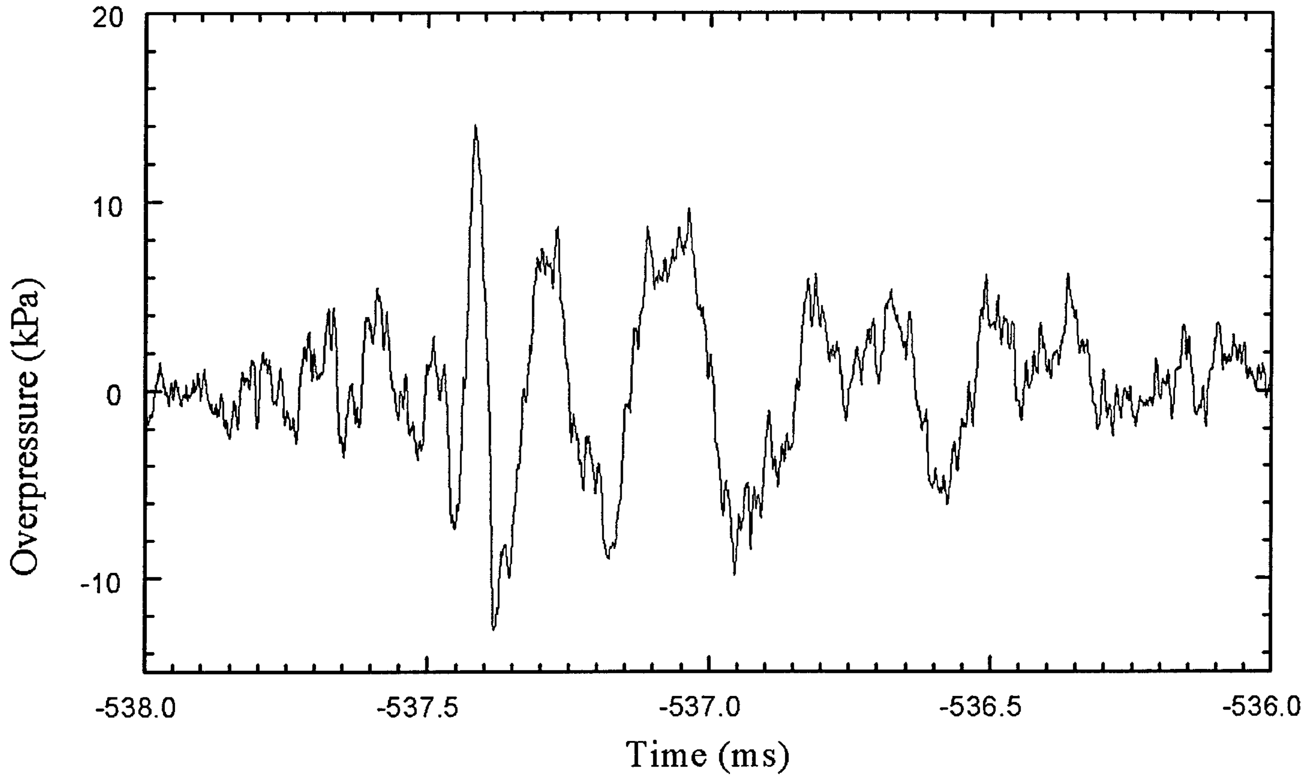
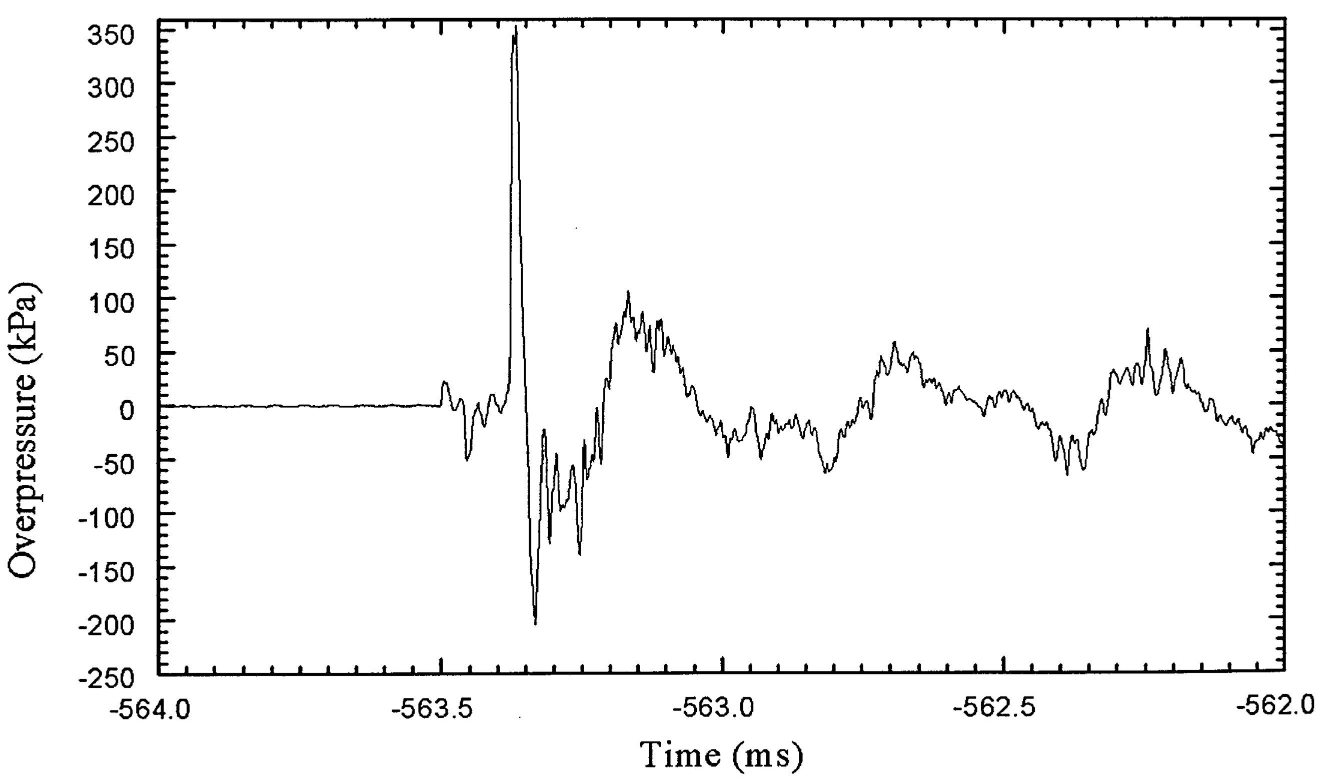


Event No. 13 Transducer P2



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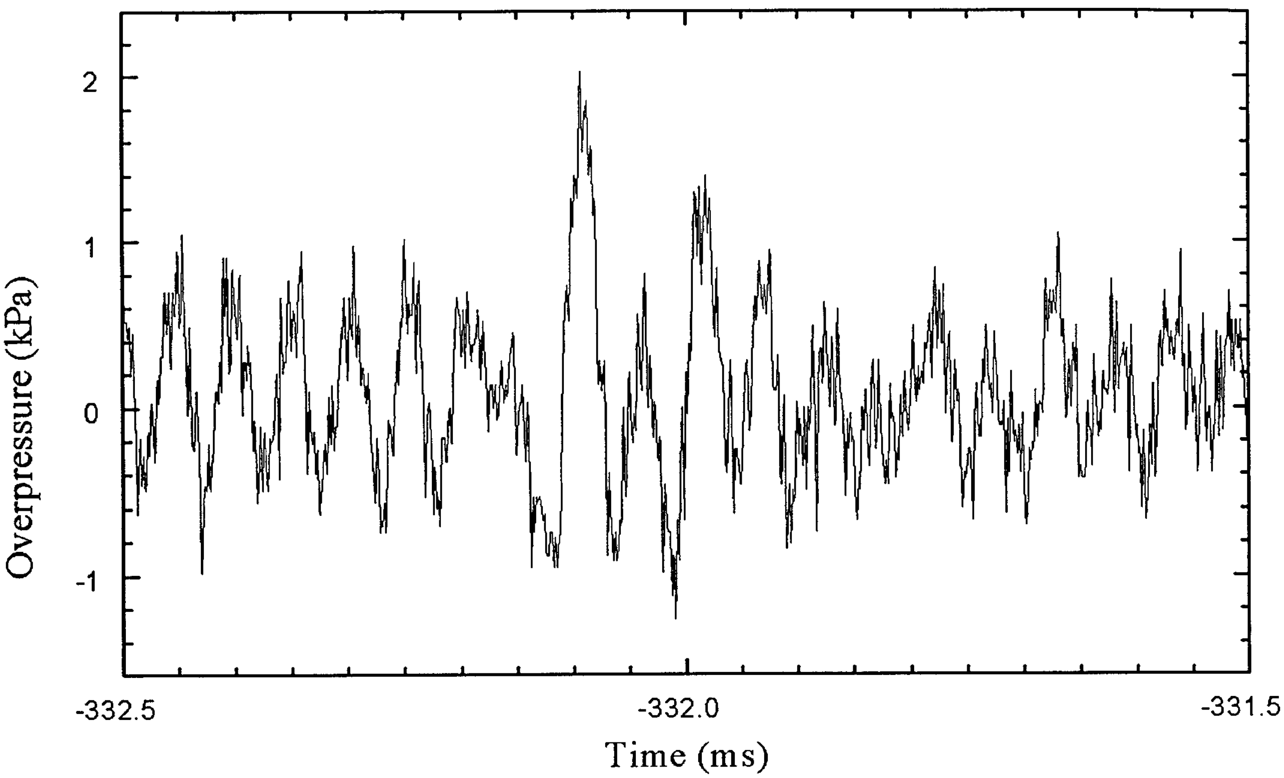
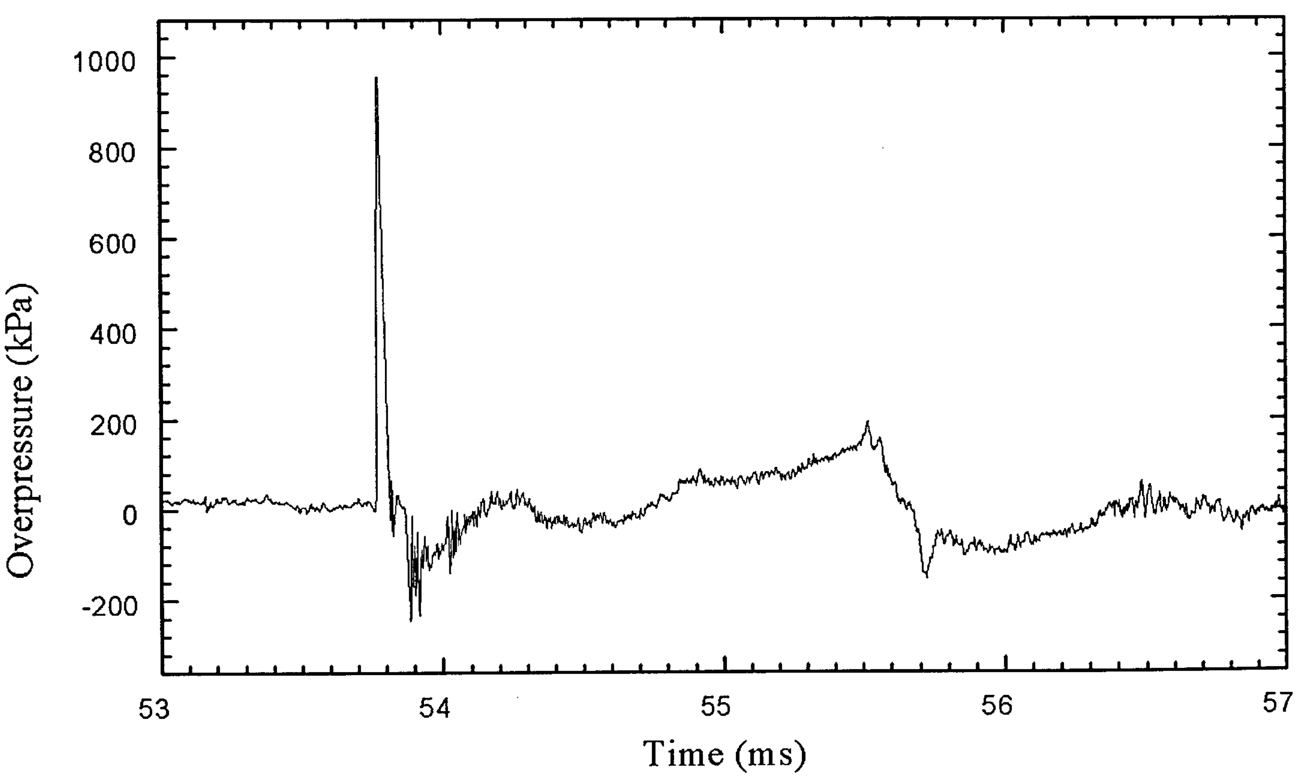
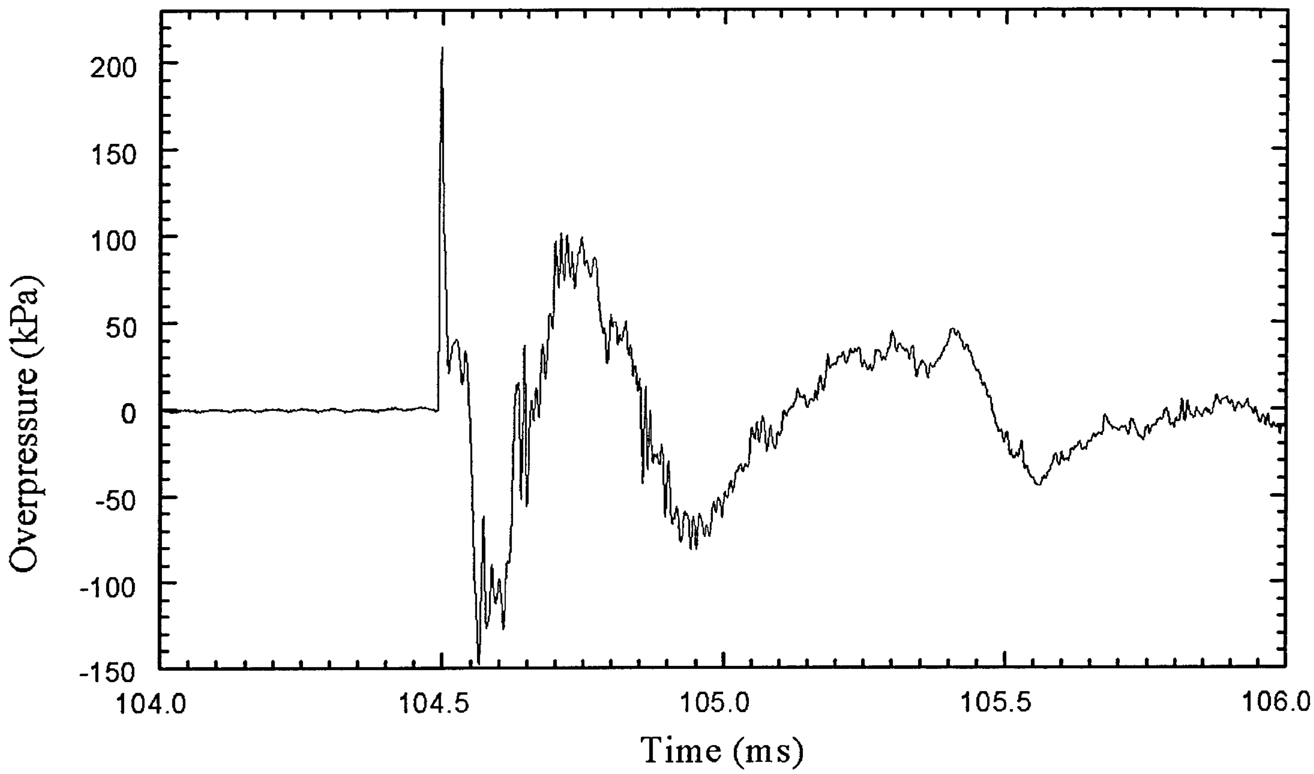


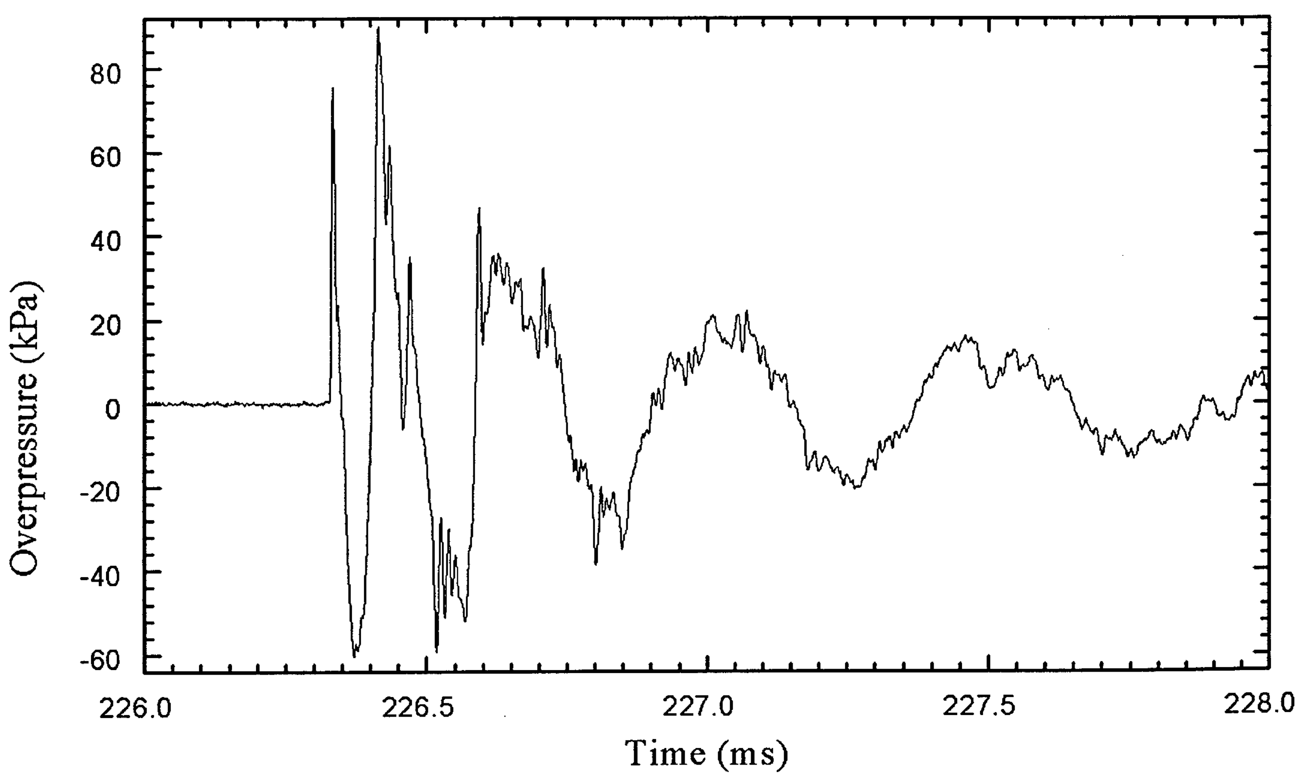
Event No. 14 Transducer P1



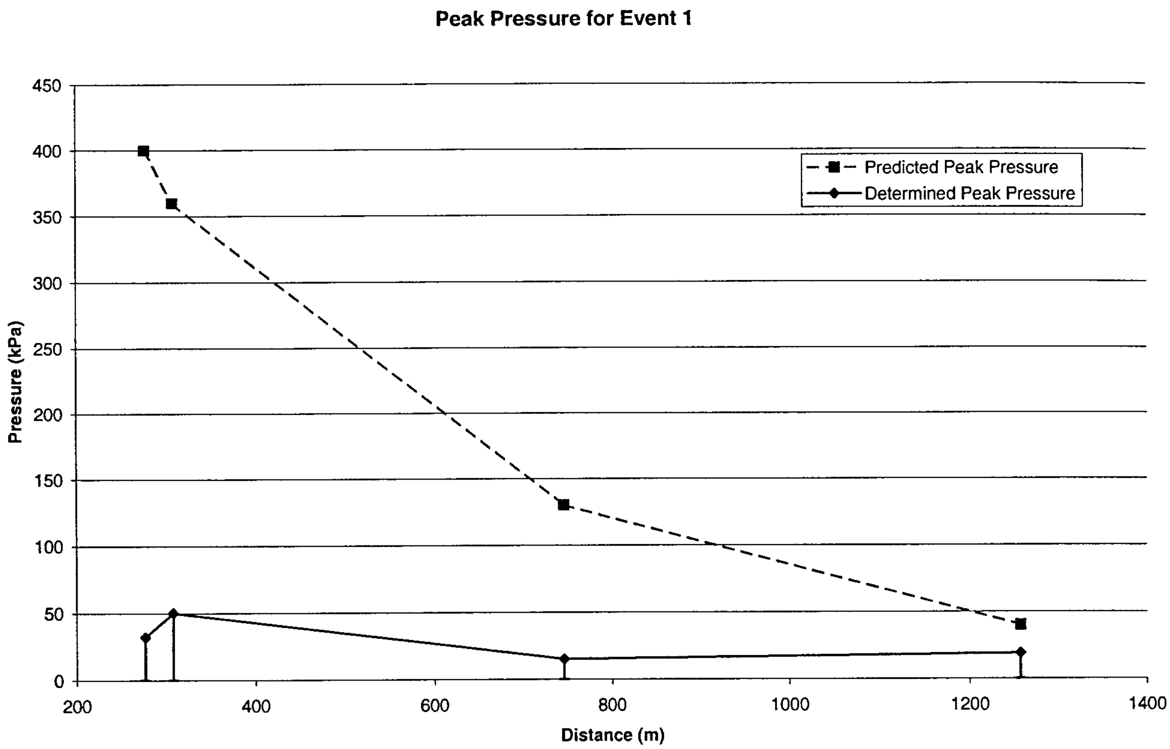
Event No. 14 Transducer P2

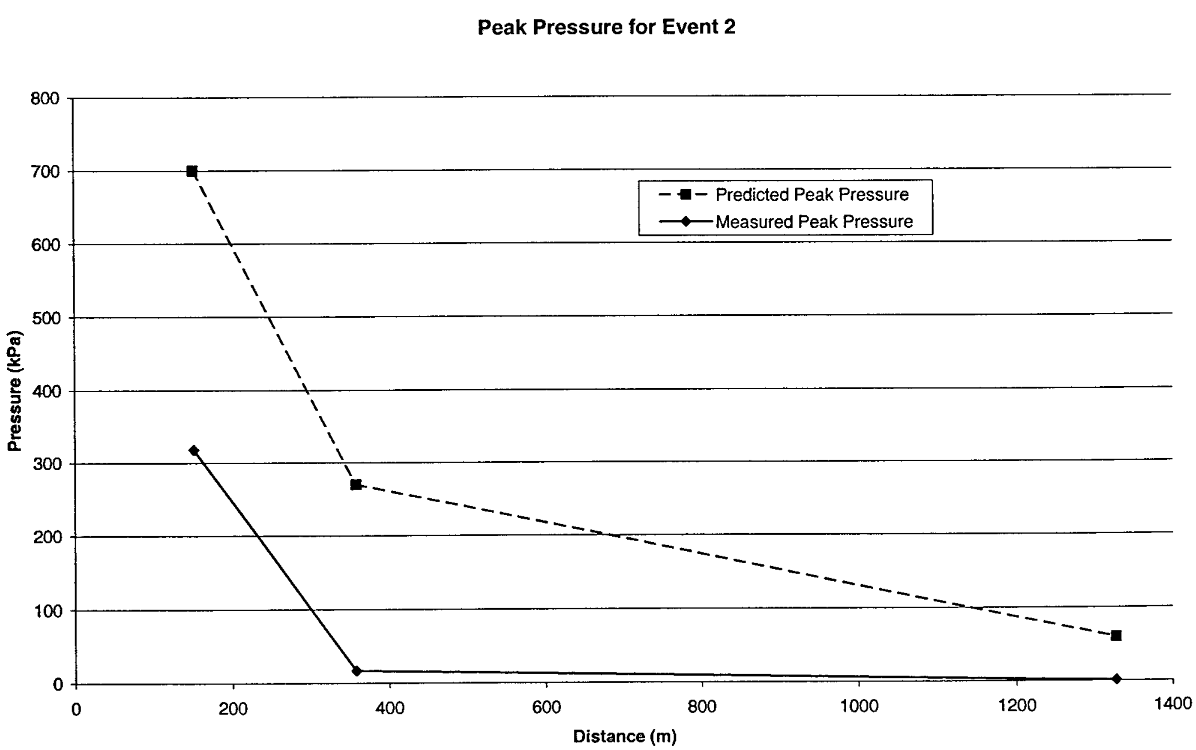


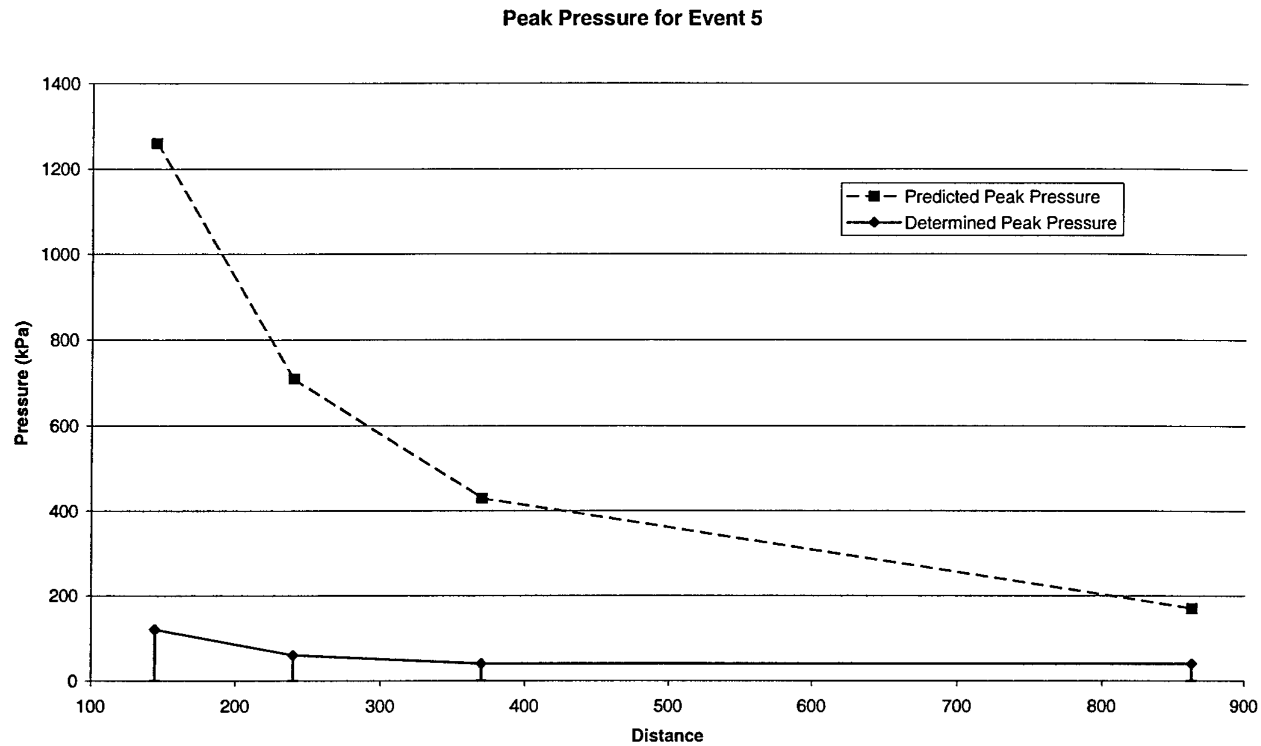
Event No. 14 Transducer P3

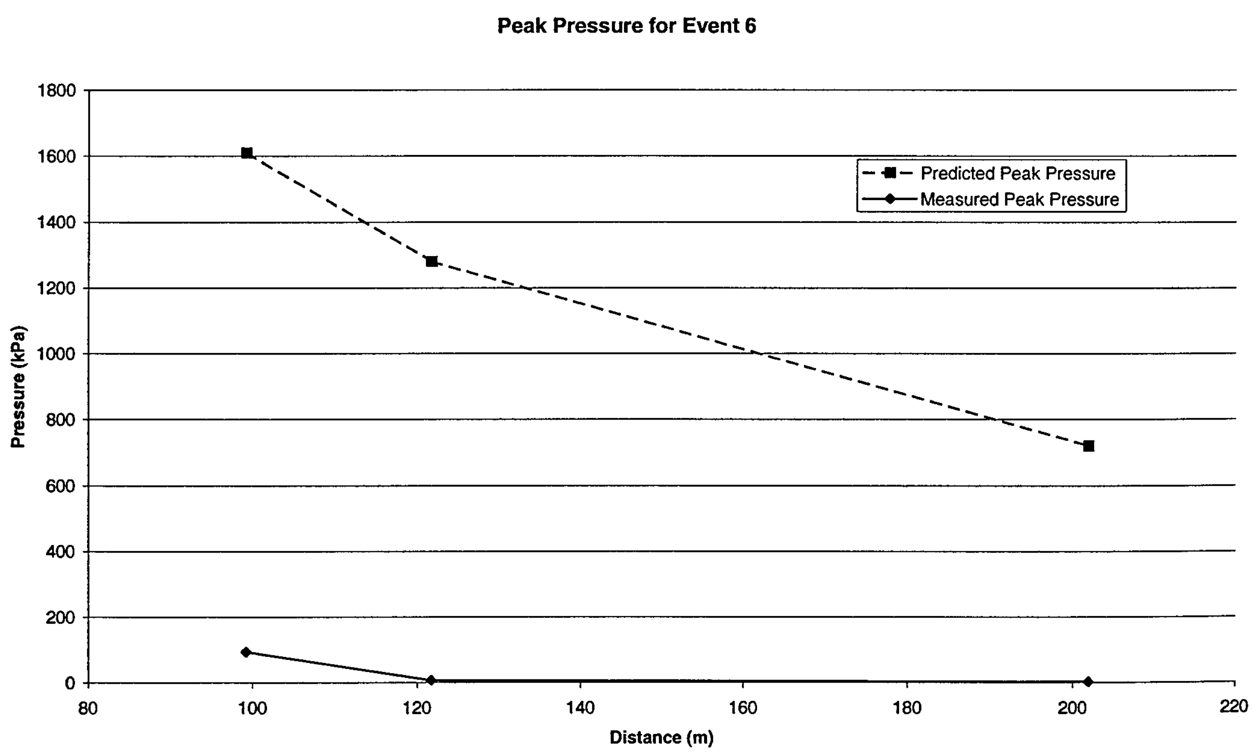


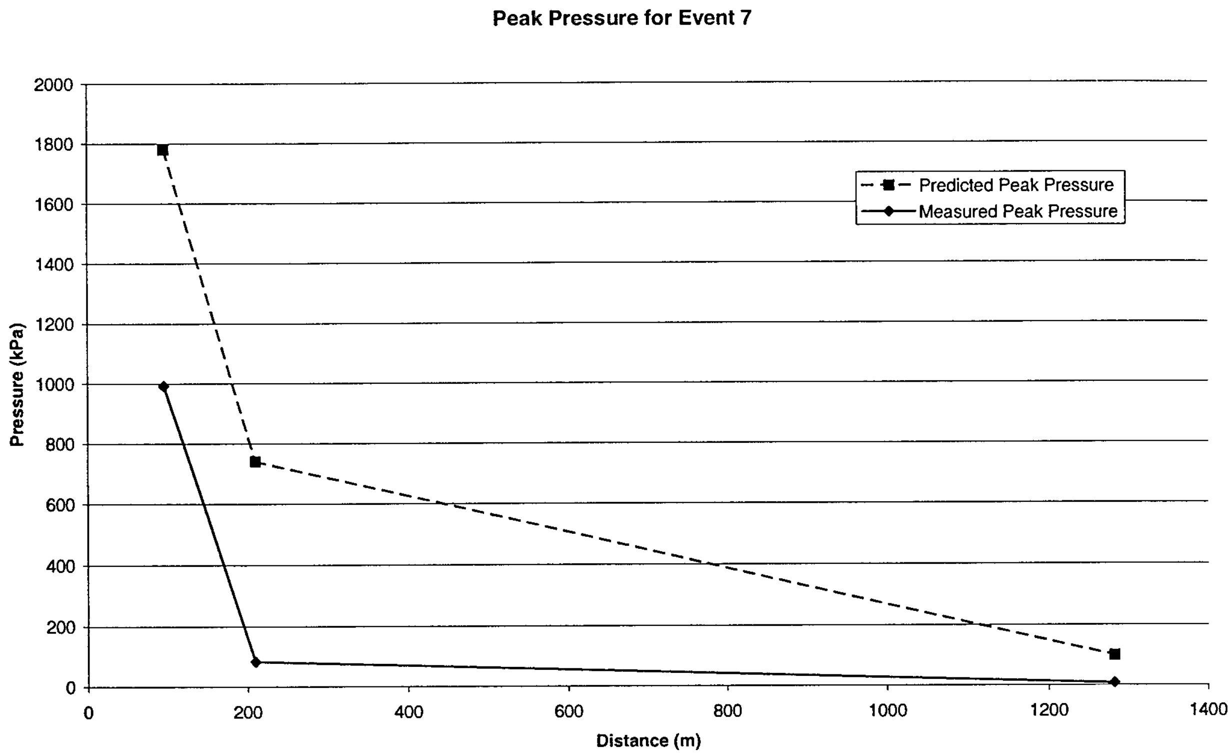
Appendix B: Peak Pressure v Distance Graphs

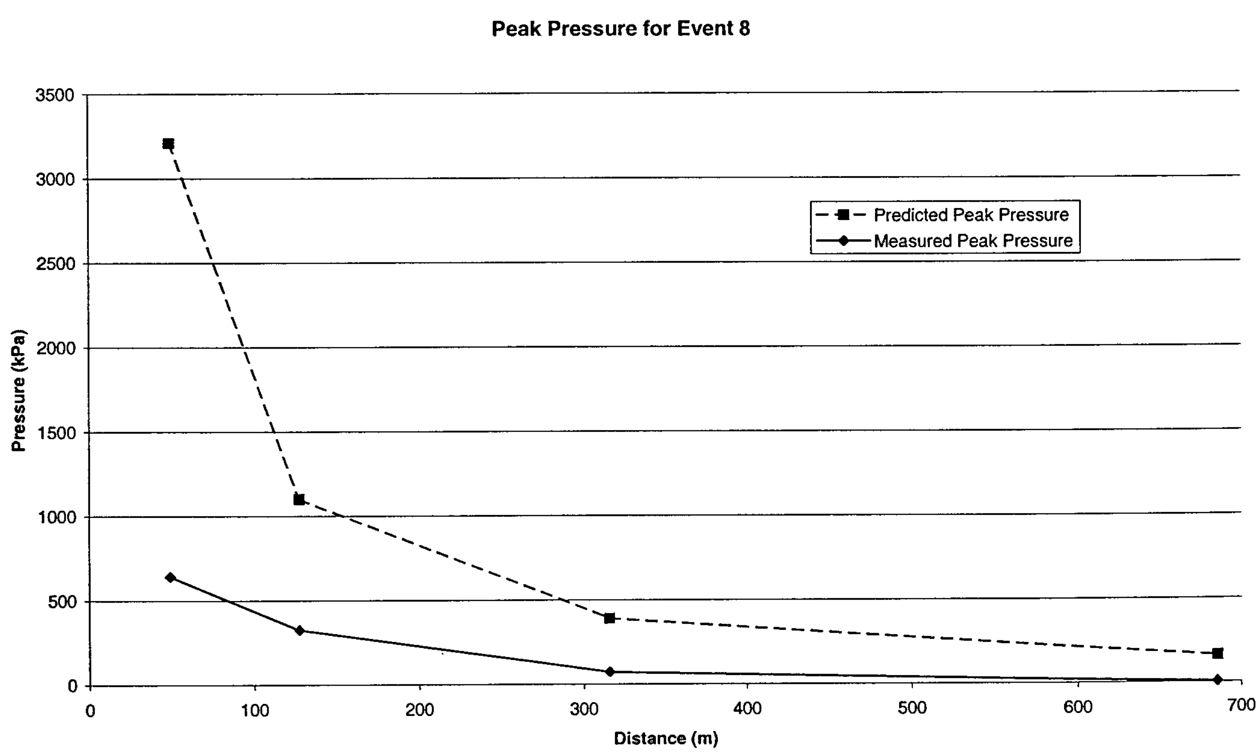

Peak Pressure for Event 1
Pressure (kPa)
Distance (m)
Predicted Peak Pressure
Determined Peak Pressure
0
50
100
150
200
250
300
350
400
450
200
400
600
800
1000
1200
1400

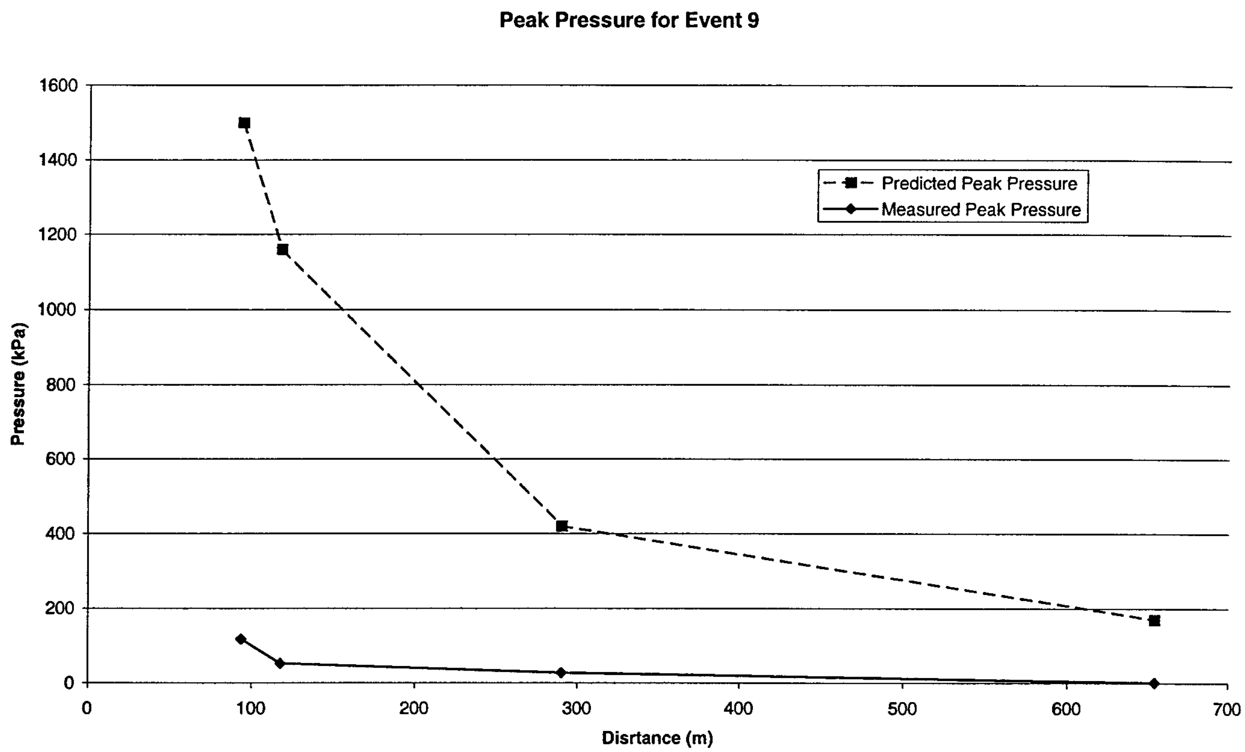

Peak Pressure for Event 2
Pressure (kPa)
Distance (m)
Predicted Peak Pressure
Measured Peak Pressure
0
100
200
300
400
500
600
700
800
0
200
400
600
800
1000
1200
1400

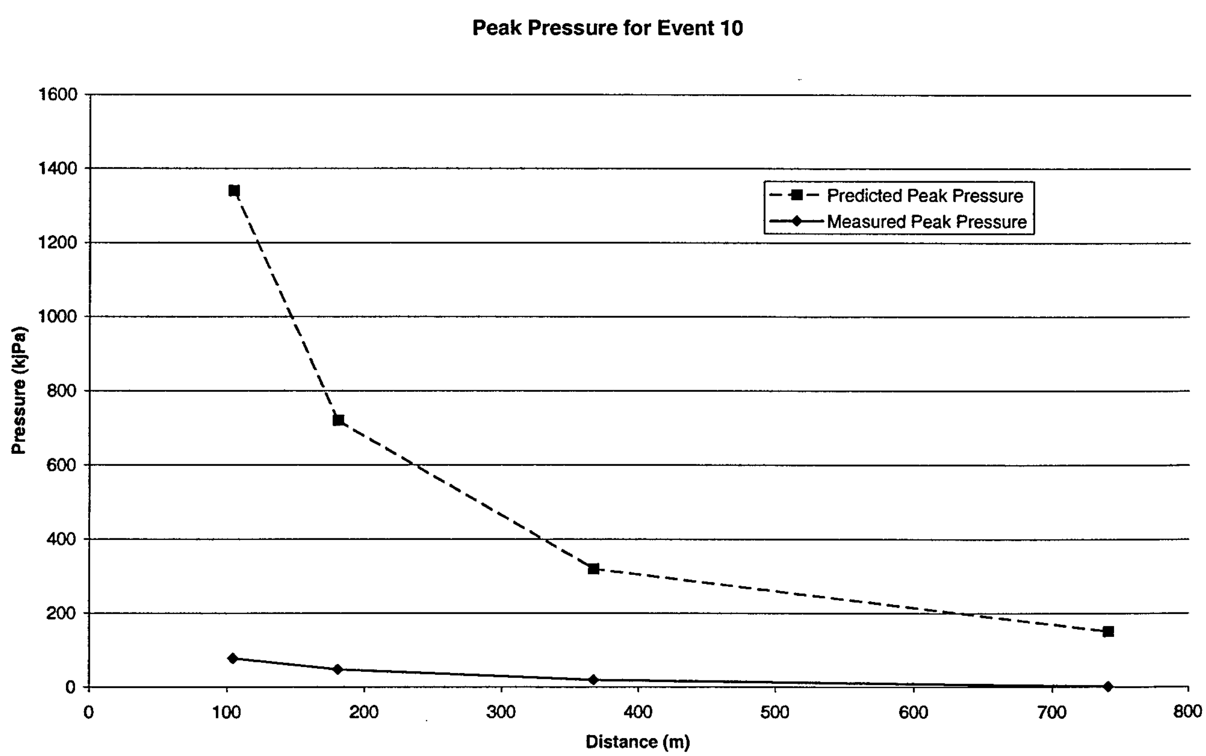

Peak Pressure for Event 5
Predicted Peak Pressure
Determined Peak Pressure
Pressure (kPa)
Distance
0
200
400
600
800
1000
1200
1400
100
200
300
400
500
600
700
800
900


Peak Pressure for Event 6
Predicted Peak Pressure
Measured Peak Pressure
Pressure (kPa)
Distance (m)
0
200
400
600
800
1000
1200
1400
1600
1800
80
100
120
140
160
180
200
220

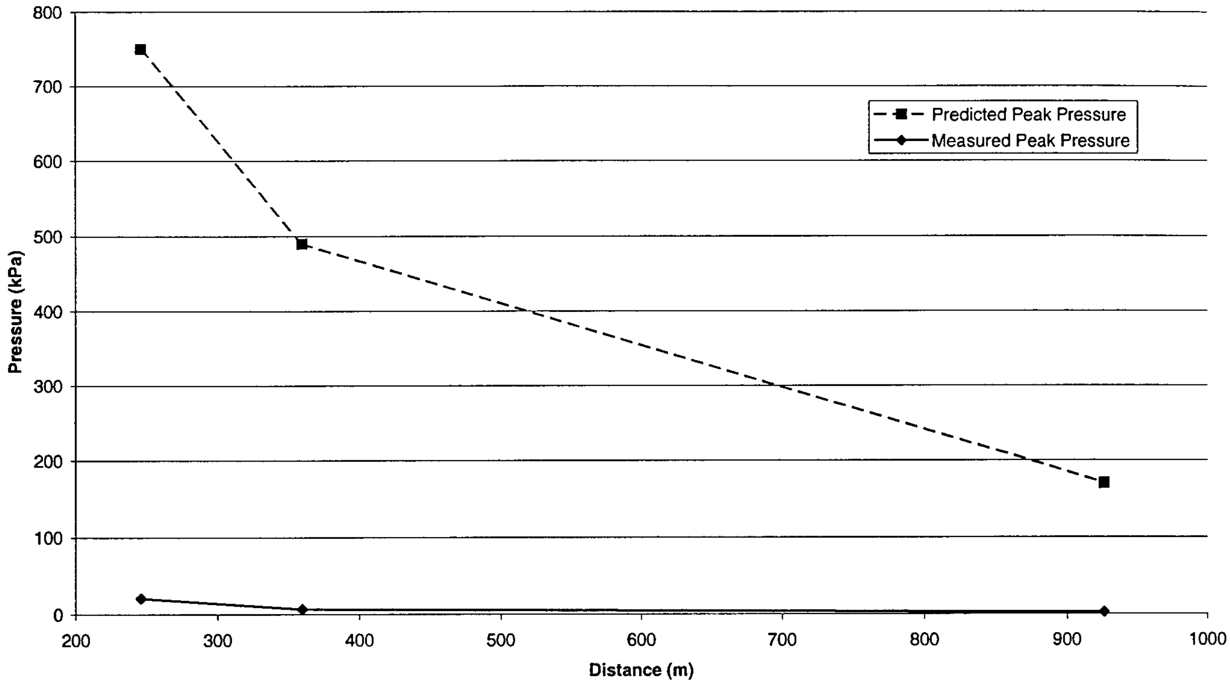

Peak Pressure for Event 7
Predicted Peak Pressure
Measured Peak Pressure
Pressure (kPa)
Distance (m)
0
200
400
600
800
1000
1200
1400
1600
1800
2000


Peak Pressure for Event 8
Predicted Peak Pressure
Measured Peak Pressure
Pressure (kPa)
Distance (m)
0
500
1000
1500
2000
2500
3000
3500
100
200
300
400
500
600
700

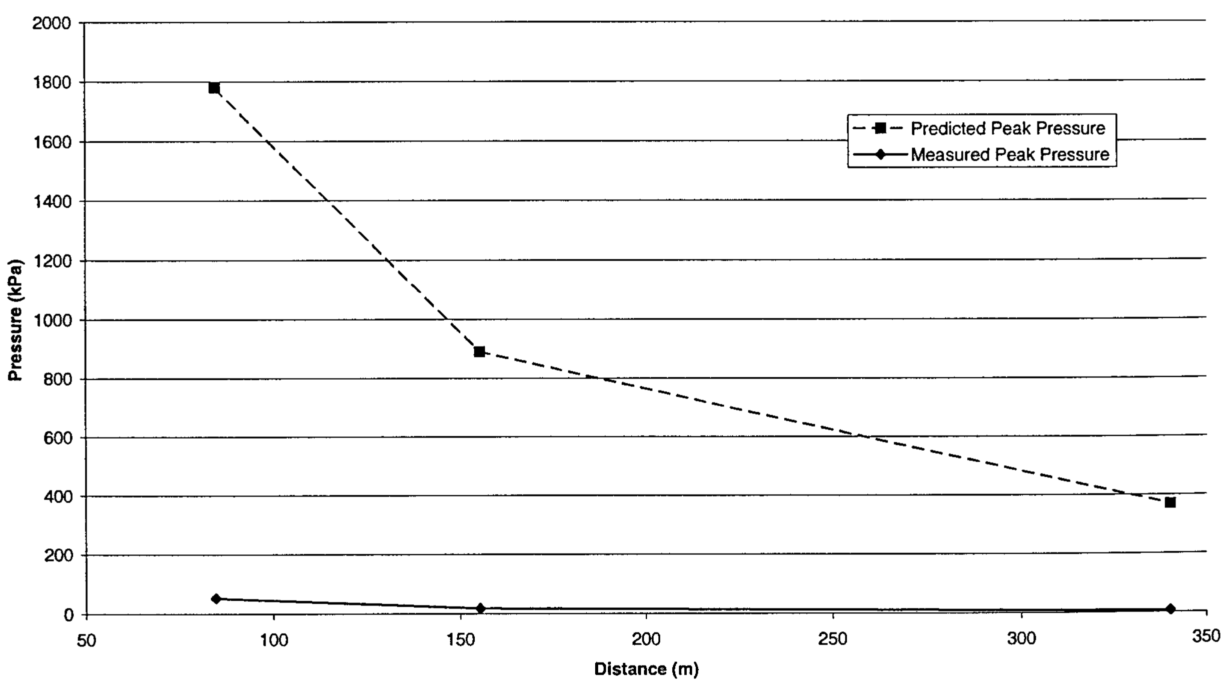

Peak Pressure for Event 9
1600
1400
1200
1000
800
600
400
200
0
Pressure (kPa)
0
100
200
300
400
500
600
700
Disrtance (m)
Predicted Peak Pressure
Measured Peak Pressure

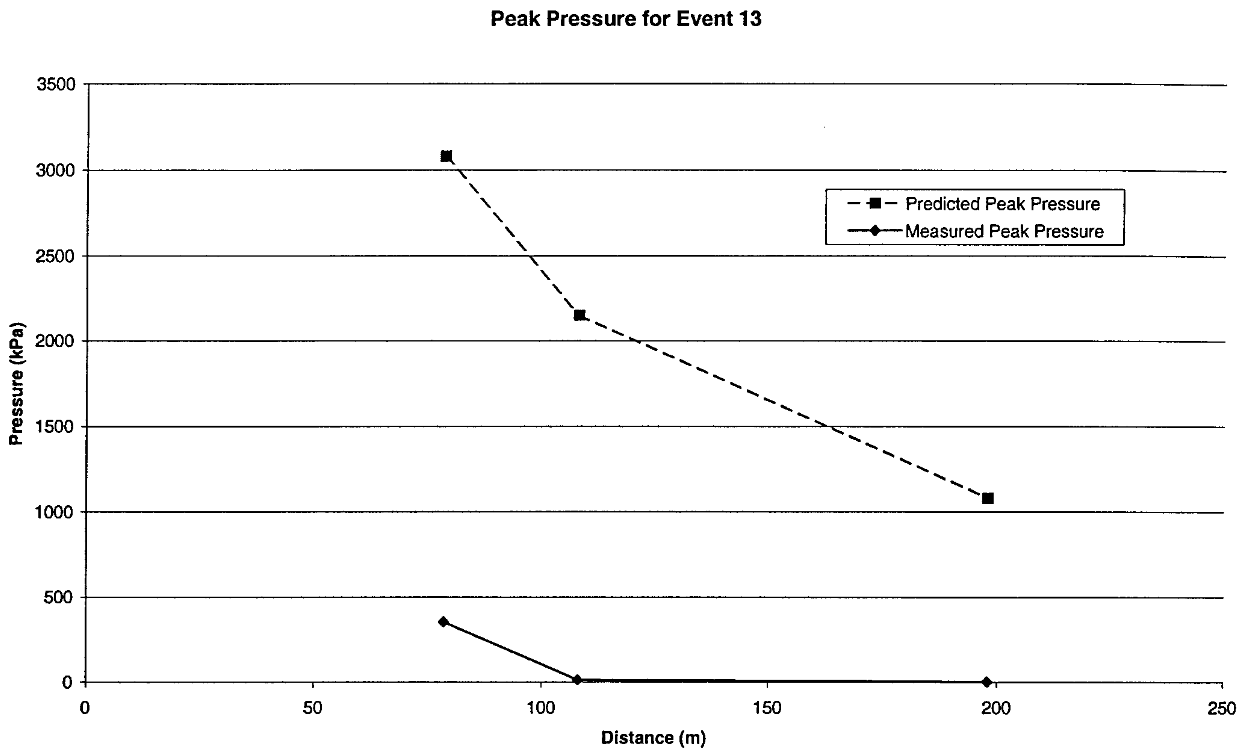

Peak Pressure for Event 10
1600
1400
1200
1000
800
600
400
200
0
Pressure (kjPa)
0
100
200
300
400
500
600
700
800
Distance (m)
Predicted Peak Pressure
Measured Peak Pressure

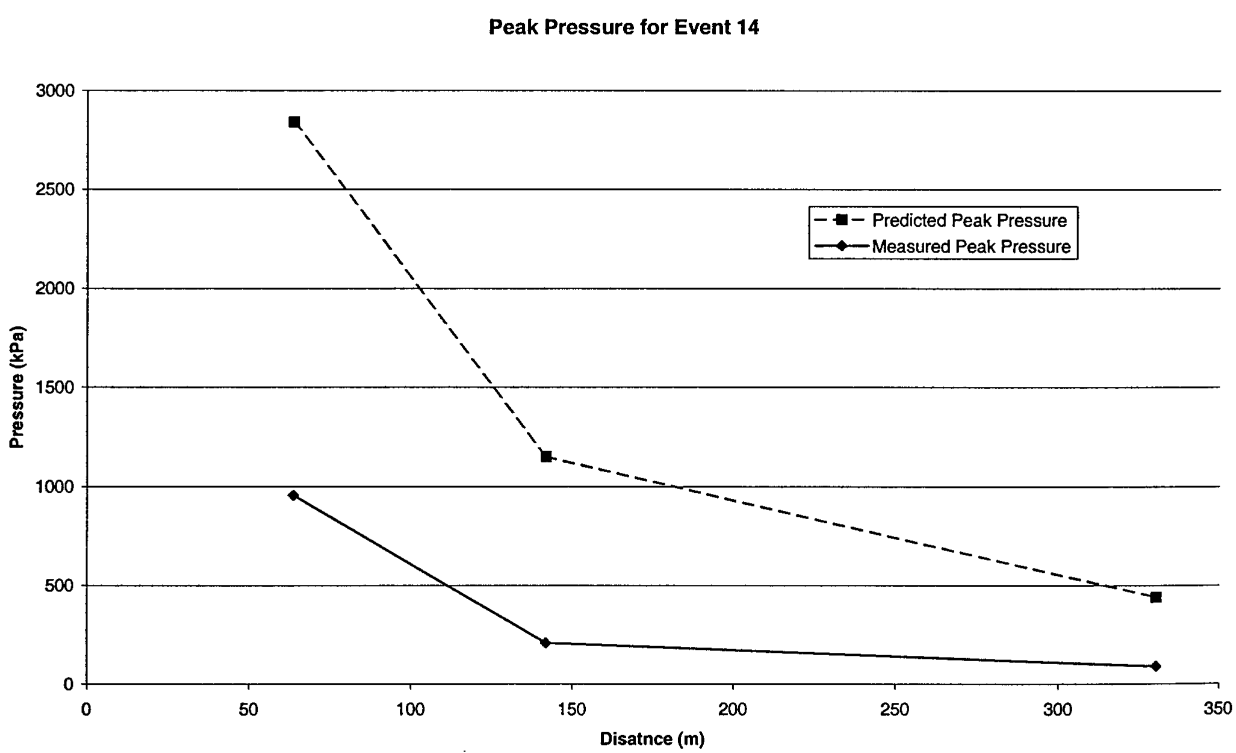
Peak Pressure for Event 11



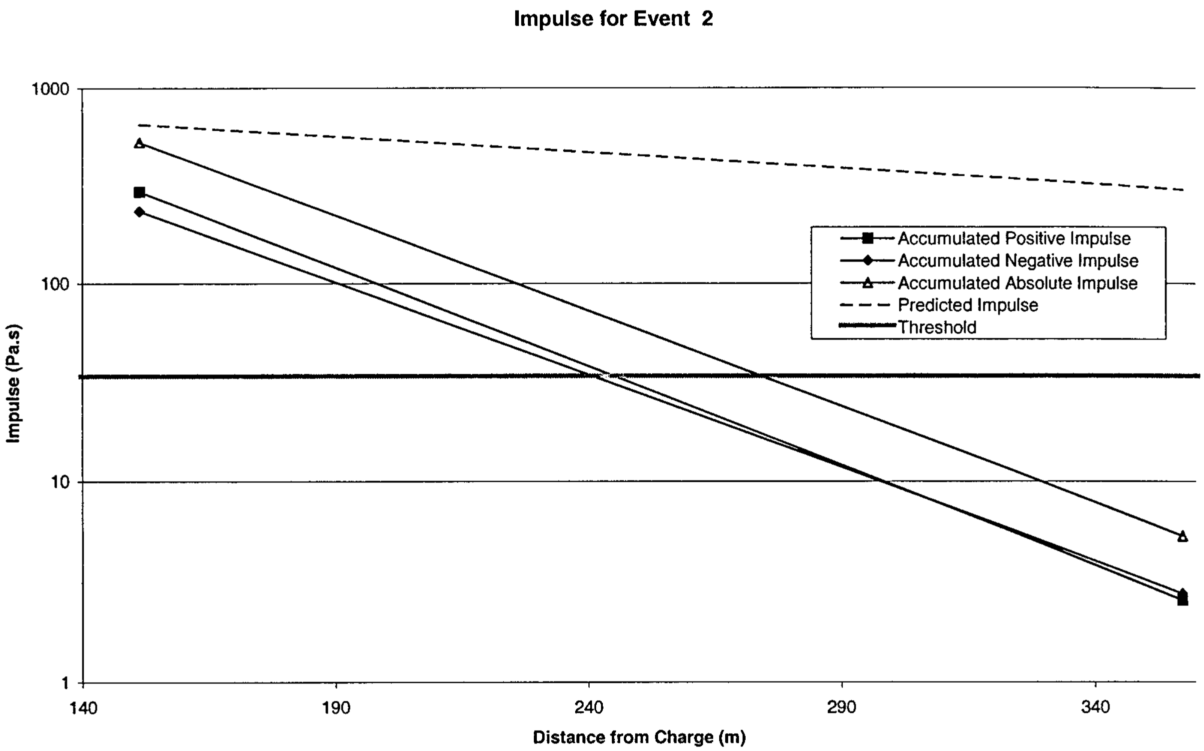
Peak Pressure for Event 12



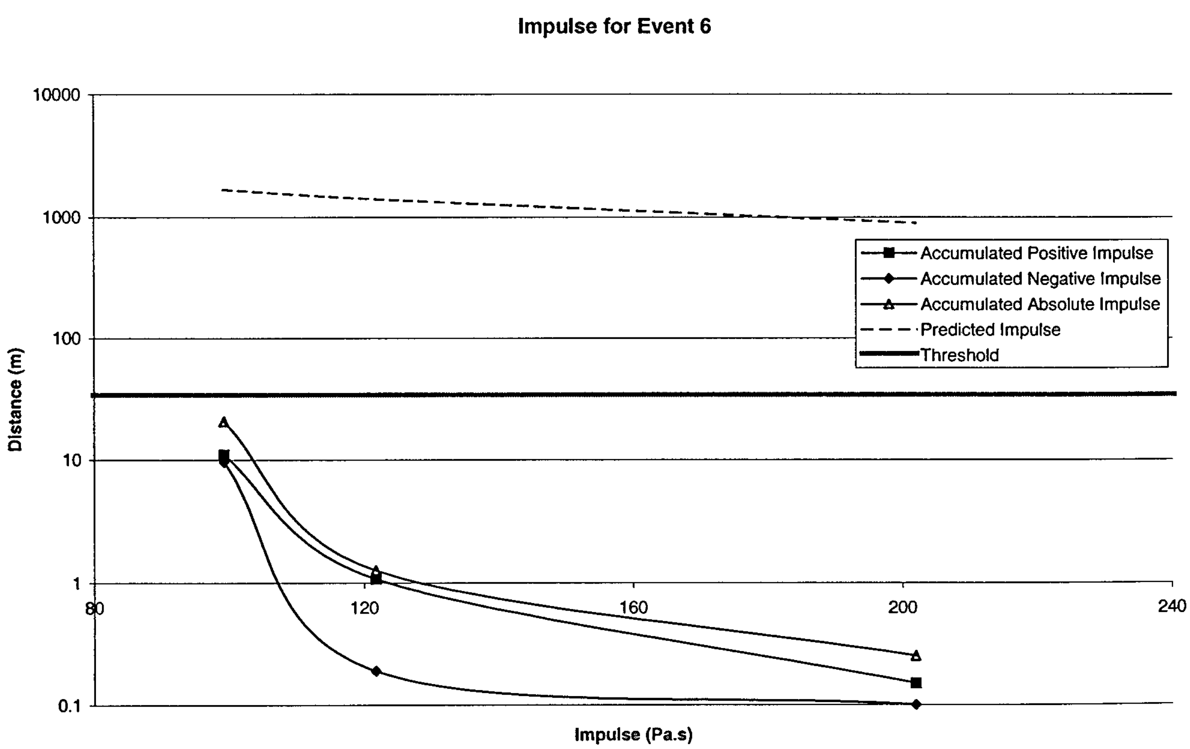

Peak Pressure for Event 13
Predicted Peak Pressure
Measured Peak Pressure
Pressure (kPa)
3500
3000
2500
2000
1500
1000
500
0
0
50
100
150
200
250
Distance (m)


Peak Pressure for Event 14
Predicted Peak Pressure
Measured Peak Pressure
Pressure (kPa)
3000
2500
2000
1500
1000
500
0
0
50
100
150
200
250
300
350
Disatnce (m)

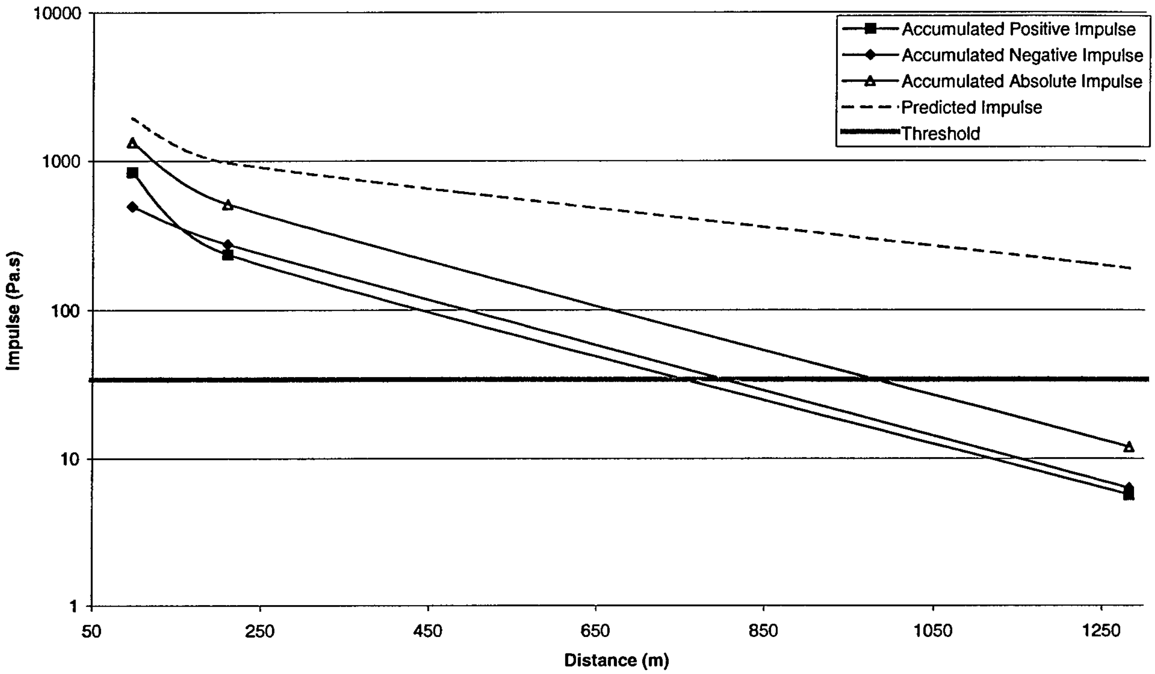
Appendix C: Impulse v Distance Graphs


Impulse for Event 2
1000
100
10
1
140
190
240
290
340
Impulse (Pa.s)
Distance from Charge (m)
Accumulated Positive Impulse
Accumulated Negative Impulse
Accumulated Absolute Impulse
Predicted Impulse
Threshold

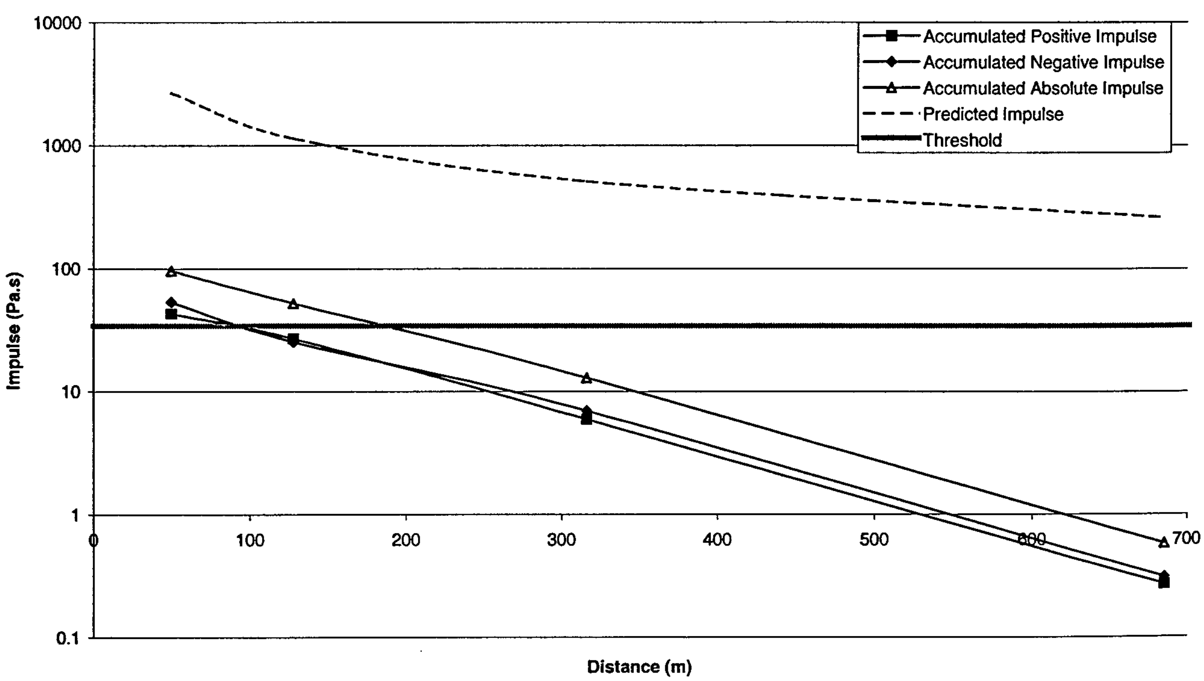
Appendix D:

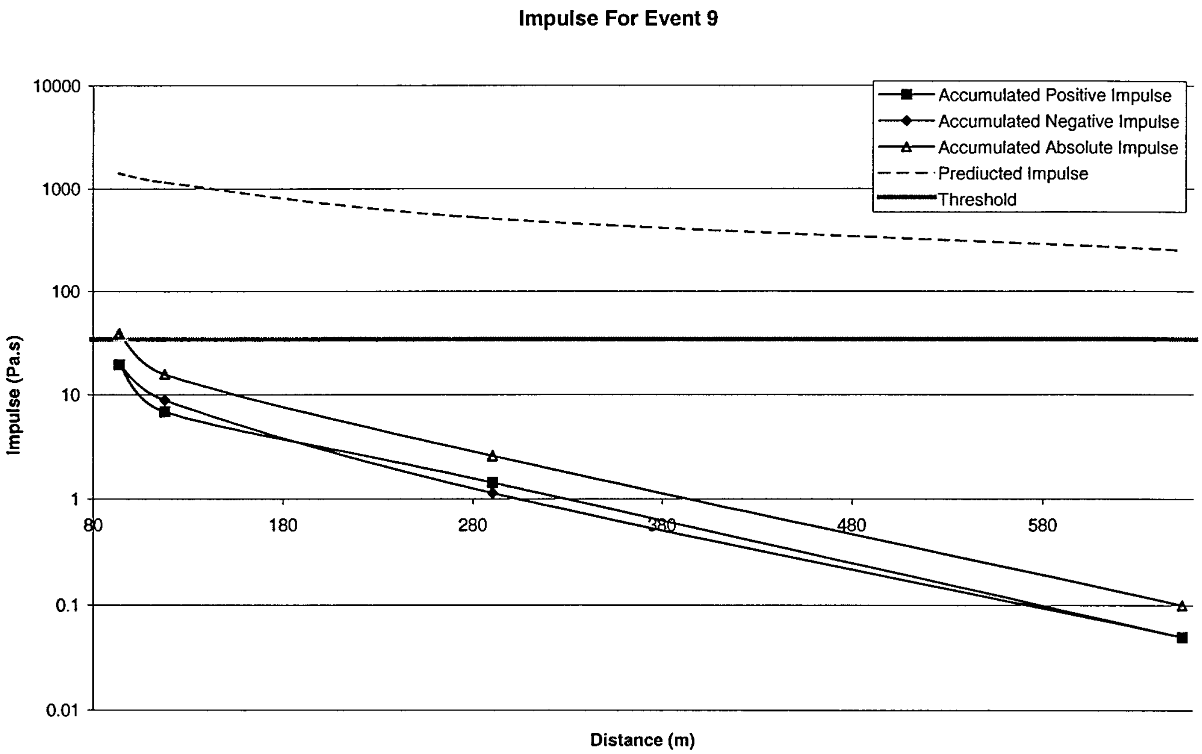

Impulse for Event 6
10000
1000
100
10
1
0.1
80
120
160
200
240
Distance (m)
Impulse (Pa.s)
Accumulated Positive Impulse
Accumulated Negative Impulse
Accumulated Absolute Impulse
Predicted Impulse
Threshold

Impulse for Event 7

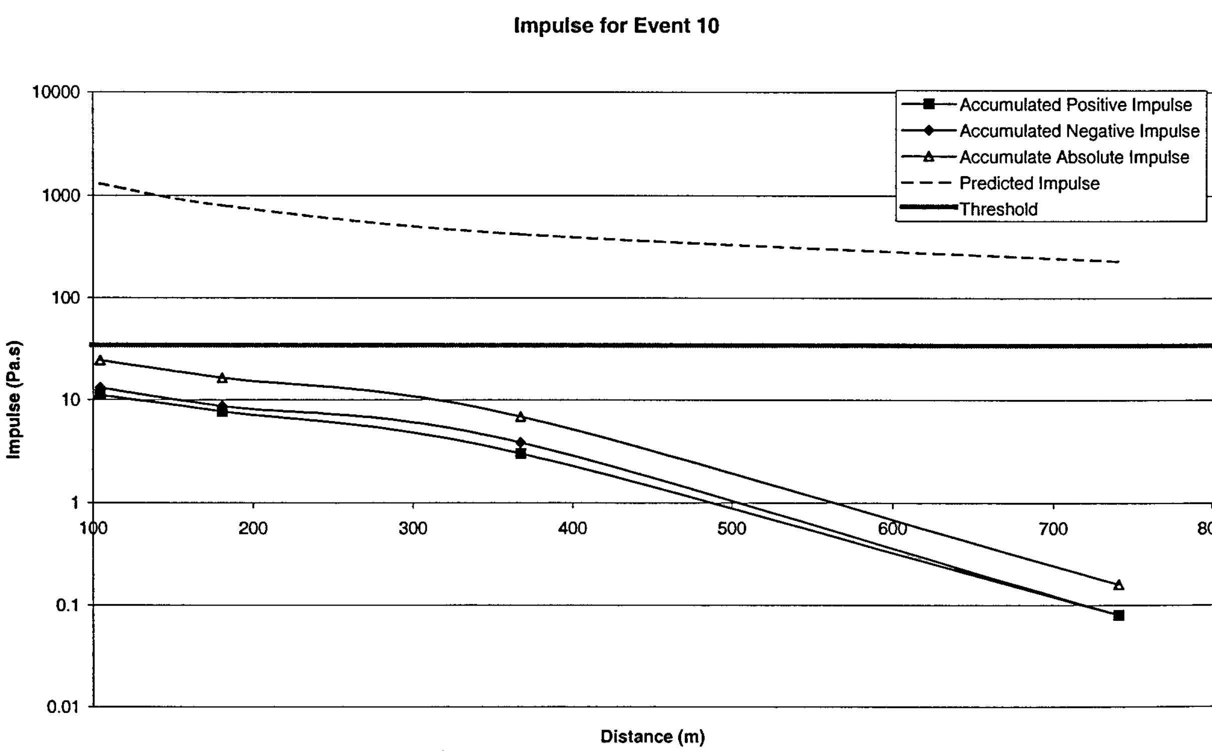


Impulse for Event 8

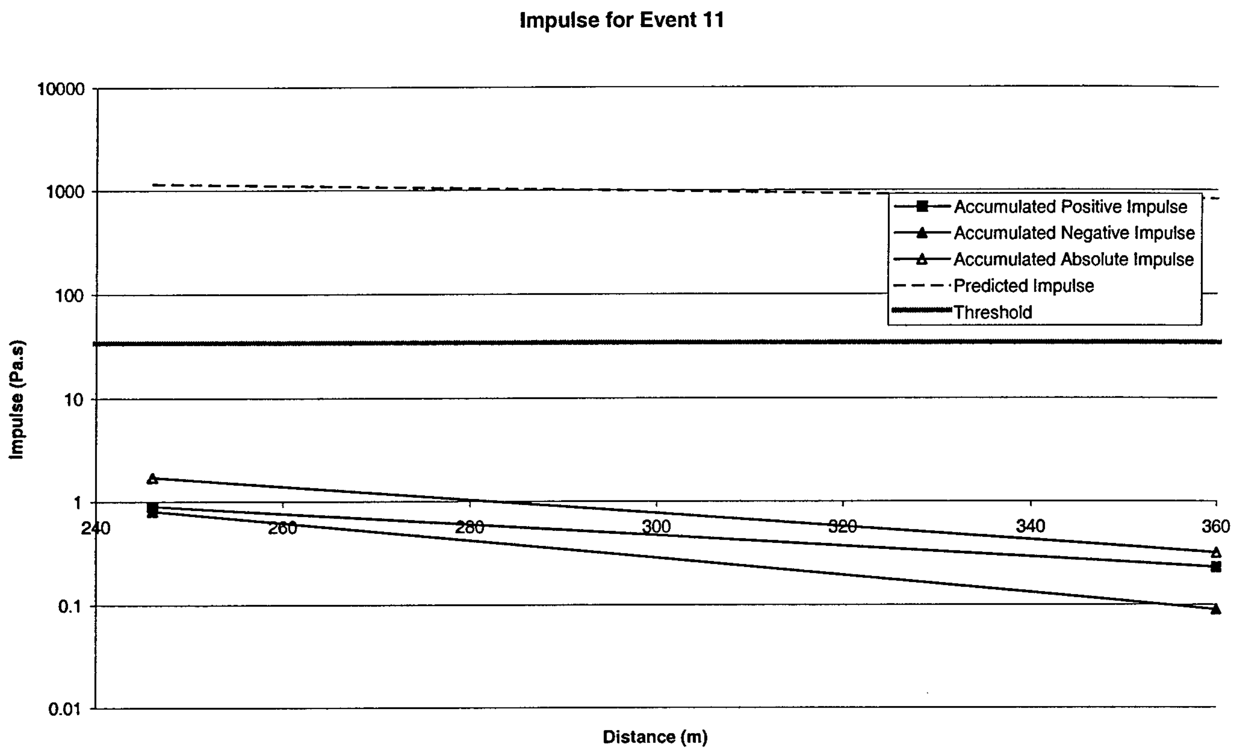


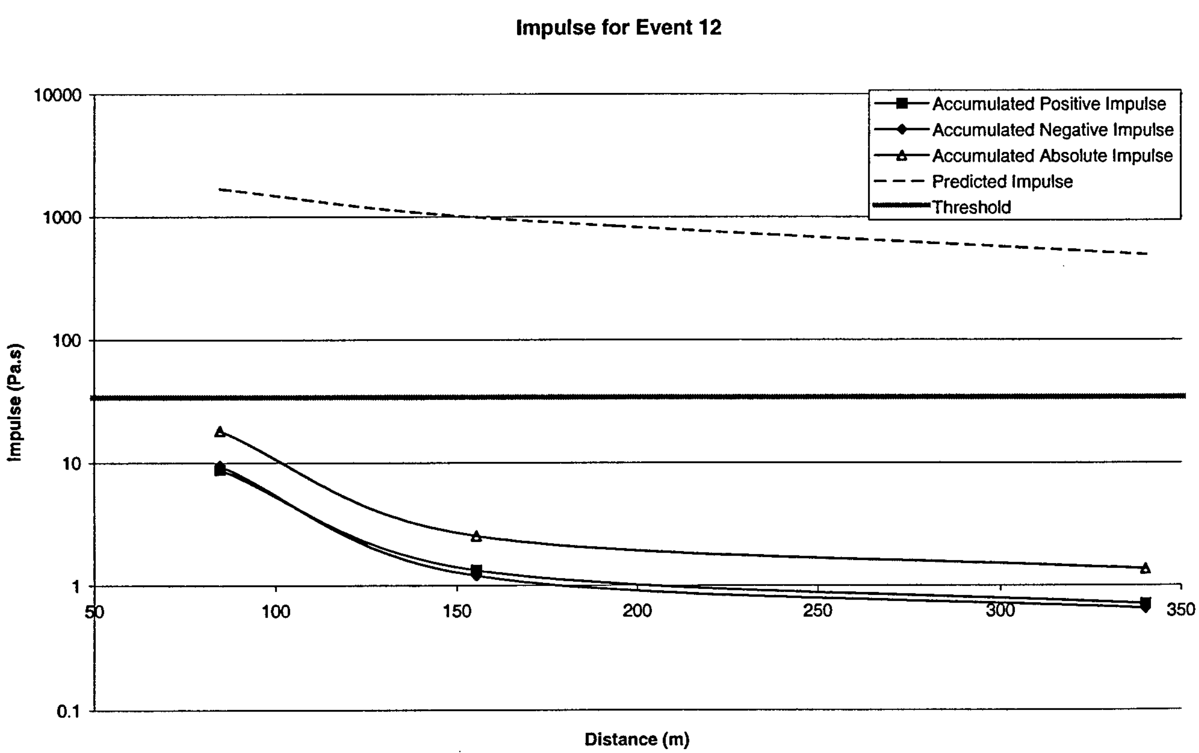


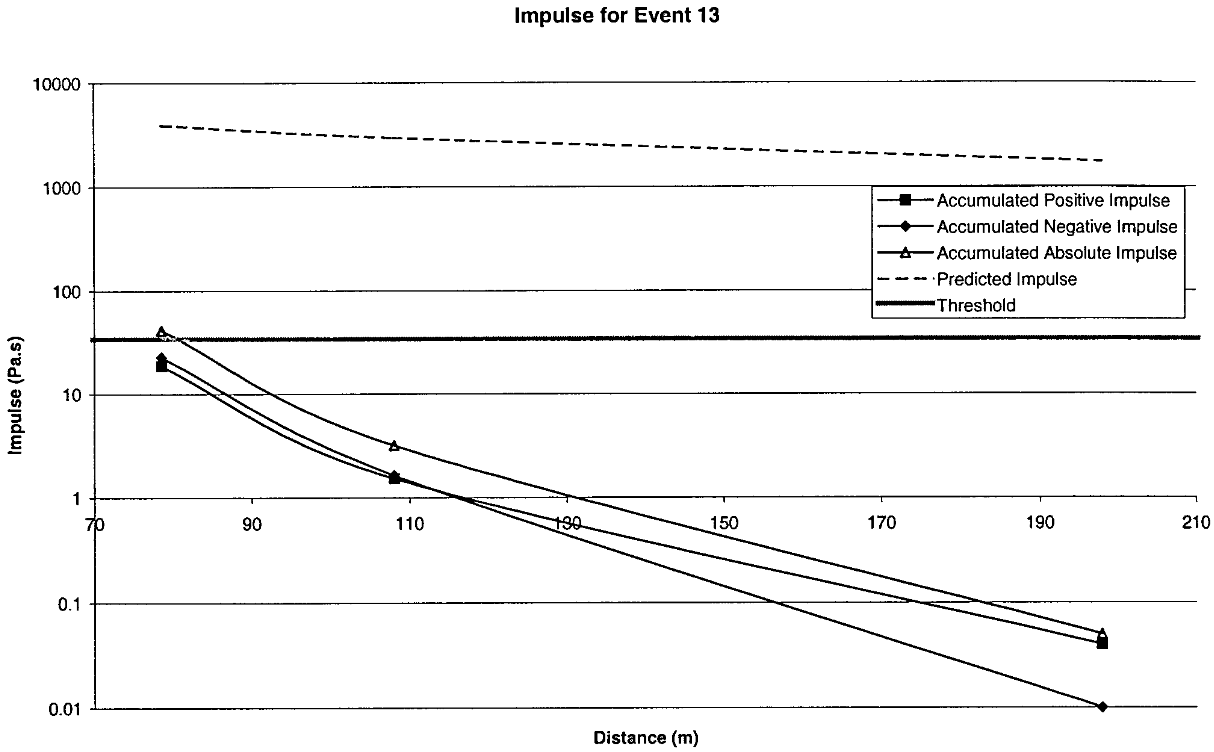
Impulse For Event 9
10000
1000
100
10
1
0.1
0.01
80
180
280
380
480
580
Impulse (Pa.s)
Distance (m)
Accumulated Positive Impulse
Accumulated Negative Impulse
Accumulated Absolute Impulse
Prediucted Impulse
Threshold

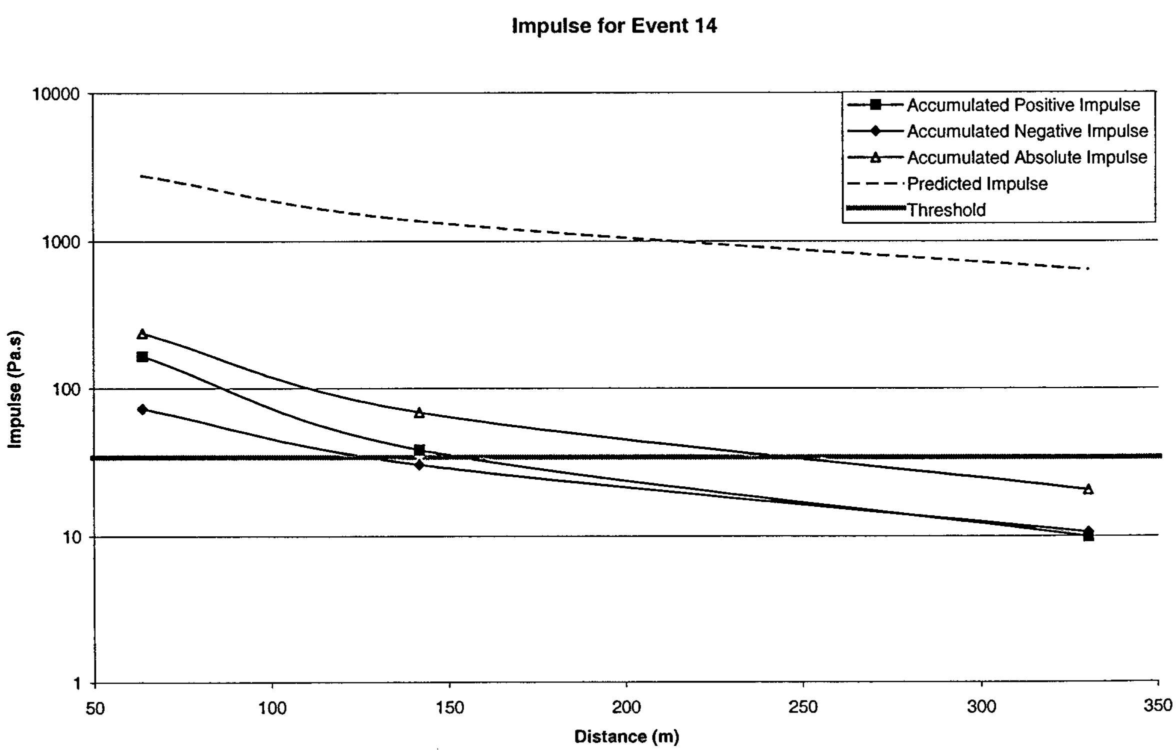


Impulse for Event 10
10000
1000
100
10
1
0.1
0.01
100
200
300
400
500
600
700
800
Impulse (Pa.s)
Distance (m)
Accumulated Positive Impulse
Accumulated Negative Impulse
Accumulate Absolute Impulse
Predicted Impulse
Threshold


Impulse for Event 11
10000
1000
100
10
1
0.1
0.01
240
260
280
300
320
340
360
Impulse (Pa.s)
Distance (m)
Accumulated Positive Impulse
Accumulated Negative Impulse
Accumulated Absolute Impulse
Predicted Impulse
Threshold


Impulse for Event 12
10000
1000
100
10
1
0.1
50
100
150
200
250
300
350
Impulse (Pa.s)
Distance (m)
Accumulated Positive Impulse
Accumulated Negative Impulse
Accumulated Absolute Impulse
Predicted Impulse
Threshold


Impulse for Event 13
10000
1000
100
10
1
0.1
0.01
Impulse (Pa.s)
70
90
110
130
150
170
190
210
Distance (m)
Accumulated Positive Impulse
Accumulated Negative Impulse
Accumulated Absolute Impulse
Predicted Impulse
Threshold


Impulse for Event 14
10000
1000
100
10
1
Impulse (Pa.s)
50
100
150
200
250
300
350
Distance (m)
Accumulated Positive Impulse
Accumulated Negative Impulse
Accumulated Absolute Impulse
Predicted Impulse
Threshold

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18. DEFTEST DESCRIPTORS

Underwater explosions, Shock waves, Animal ecology

19. ABSTRACT

Defence training in Shoalwater Bay, Queensland includes the training of RAN clearance divers in underwater explosives demolition. Shoalwater Bay is also a significant dugong habitat and concerns have been raised about the impact of diver training on resident dugong.
Shock parameters resulting from underwater detonations during a clearance diver training exercise were measured. The methodology, results, analysis and recommendations are presented.